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TESTING AMPLIFIER OUTPUT VALVES BY MEANS OF THE CATHODE RAY TUBE

by A. J. HEINS van der VEN.

621.317.755 : 621.396.645

In testing amplifier output valves, the most important data are contained in the I_a-V_a diagram if one knows over which part of the diagram the values of voltage and current prevailing during operation range, *i.e.* if the position of the load line is known. The I_a-V_a diagrams as well as the load lines can very easily be obtained with the help of a cathode ray tube. The necessary apparatus is described in this article. A number of auxiliary arrangements are also studied, by which the axes and the necessary calibration lines in the diagram can be traced on the fluorescent screen, and which make it possible to cause the diagrams of two output valves which are to be compared to appear simultaneously on the screen. In order to obtain the load line in the correct place in the diagram, use must be made of direct current push-pull amplifiers for the deflection voltages of the cathode ray tube. The position of the load line upon inductive loading is discussed and explained by a number of examples. In conclusion one application of the installation in the development of output pentodes is dealt with.

If one wishes to characterize briefly the performance of an output valve of an amplifier or radio set, it is enough to give the sensitivity, the distortion as a function of the power output, and in some cases the maximum power which can be delivered without grid current flowing. For a more careful examination, however, particularly for the discovery of causes of deviations or errors, such for example as differences in distortion in different valves, one must in general have reference to the I_a-V_a diagram, which forms the actual basis for the judgement of the properties of an output valve. This diagram (*fig. 1*) gives the variation of the anode current I_a as a function of the anode voltage V_a with the negative control grid voltage V_g as parameter [1]). From the series of curves the primary quantities of the valve: slope, internal resistance and amplification factor, may be read off immediately for every operating point, as is explained in the text under the figure. A connection may, however, also be found between the shape of the curve and the above-mentioned quantities such as distortion and power output. Since these quantities are to some degree dependent on the loading impedance which is included in the anode circuit, it is first necessary to find out how the loading of the valve is expressed in the I_a-V_a curve.

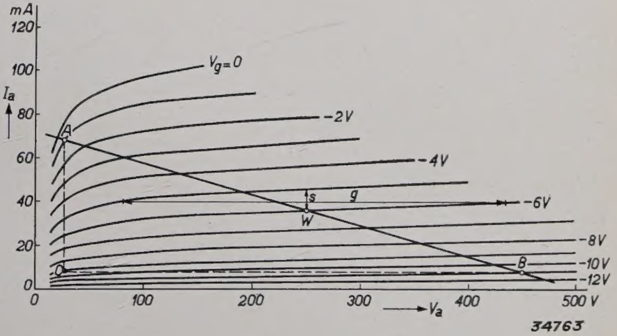

Fig. 1. The I_a-V_a diagram of the output valve EL_3. *W* is the operating point; in this valve it ordinarily lies at V_a = 250 volts, I_a = 36 mA, V_g = −6 volts. The screen grid voltage is permanently fixed at 250 volts. The slope *S* is given by the vertical distance between two successive curves, the amplification factor *g* by the corresponding horizontal distance, the internal resistance by the slope of the I_a-V_a curve at the operating point. *AB* is the load line for a pure resistance of 7 000 ohms.

If the valve is loaded with a resistance *R* which is connected to the anode circuit through a transformer in order to have no D.C. voltage drop in *R* (*fig. 2*), an alternating current I_R will begin to flow in R when an A.C. voltage is applied to the grid of the valve. The A.C. voltage on the loading resistance is then $V_R = R \cdot I_R$. The total anode voltage V_a and anode current I_a of the valve are given by the sum of V_R or I_R and the values of the anode D.C. voltage or current indicated by the operating point. The relation between I_a and V_a of the loaded valve, the socalled load line, is therefore in this case represented by a straight line through the operating point (AB in fig. 1), with the slope $\tan \alpha = R$ with respect to the I_a axis.

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[1]) The screen grid voltage, which forms a second parameter in the case of pentodes, is kept constant for the whole diagram.

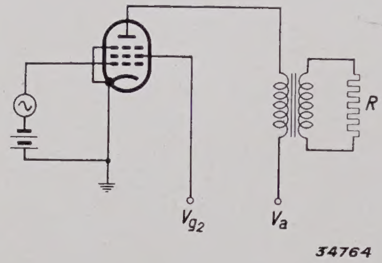

Fig. 2. A loading resistance R is included in the anode circuit of the output valve *via* a transformer 1 : 1.

If one considers the grid voltage to be varying, the values of I_a and V_a at any moment are always determined by the point of intersection of the load line with the I_a-V_a curve corresponding to the value of the grid voltage at that moment. If, for instance, the operating point lies on the curve for $V_g = -6$ volts and the grid excitation voltage is sinusoidal with a peak value of 5 volts, then the points of intersection of the line AB with the curves $V_g = -1$ volt and $V_g = -11$ volts give the extreme values of I_a and V_a. The distance AC is therefore twice the amplitude of the alternating current occurring, the distance BC twice the amplitude of the A.C. voltage. The power output to the loading resistance at the grid excitation voltage in question is thus given by $^1/_4$ of the area of the triangle ABC.

Insofar as the successive I_a-V_a curves cut off equal segments of the line AB, a proportional change in anode voltage and current corresponds to any change in the grid voltage. There is therefore no distortion. With large amplitudes along the load line, however, the segments cut off on AB become gradually smaller (fig. 1). The variation of anode voltage and current with a sinusoidal grid excitation voltage is then no longer sinusoidal, but exhibits a flattening. The distortion occurring could be calculated by careful measurement of the segments cut off on the load line.

If the loading impedance is not a pure resistance, the load line is not straight in the I_a-V_a diagram. Depending on the grid excitation voltage a larger or smaller portion of the whole diagram is then covered by the load lines. A knowledge of this region makes it possible to estimate the importance for the reproduction, of any irregularities occurring in the I_a-V_a diagram.

In the following a method will be described by which not only the I_a-V_a diagram, but also the load line can very easily be obtained. The principle of this method, which makes use of the cathode ray tube, has already been outlined in this periodical [2]), at least as far as the recording of I_a-V_a diagrams is concerned. We shall here go more deeply into the practical execution of the method and also give several examples of its application.

Installation for the recording of I_a-V_a diagrams.

An I_a-V_a characteristic can be registered on the screen of a cathode ray tube in the following way. A given D.C. voltage is applied to the control grid of the output valve to be investigated, while the anode voltage is made to vary periodically from zero to a maximum value. This anode voltage is applied, *via* a potentiometer and an amplifier, to the plates for horizontal deflection of the fluorescent spot. The voltage on a small measuring resistance, through which the anode current flows, causes the vertical deflection, which is therefore proportional to the anode current at every moment.

In order to trace different I_a-V_a curves on the screen successively, the grid bias must be given different values successively for short times. A voltage which varies in steps must therefore be applied to the grid, and in order to obtain a lasting image on the screen of the cathode ray tube, this voltage varying in steps must be run through completely several times per second.

The stepwise varying voltage is obtained by means of a rotating switch S_1 which passes over 28 contacts (*fig. 3*). Sixteen of these are connected to the taps of a potentiometer which correspond to the 15 steps of the desired voltage series, see *fig. 4*. On the following 6 contacts (*17* to *22*) there is a high negative voltage, so that the valve to be examined passes no anode current at all during this time. By this means, and by the great rapidity at which the switch rotates (1 000 to 1 500 r.p.m.) it is possible to record the whole I_a-V_a diagram without the valve becoming overloaded.

For the sake of orientation in the diagram, the two axes and the corresponding scale are necessary in addition to the I_a-V_a curves. The remaining

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[2]) H. van Suchtelen, Applications of cathode ray tubes, Philips techn. Rev. **3**, 339, 1939. See also Philips techn. Rev. **4**, 56, 1939, where a related problem had to be solved in a different way.

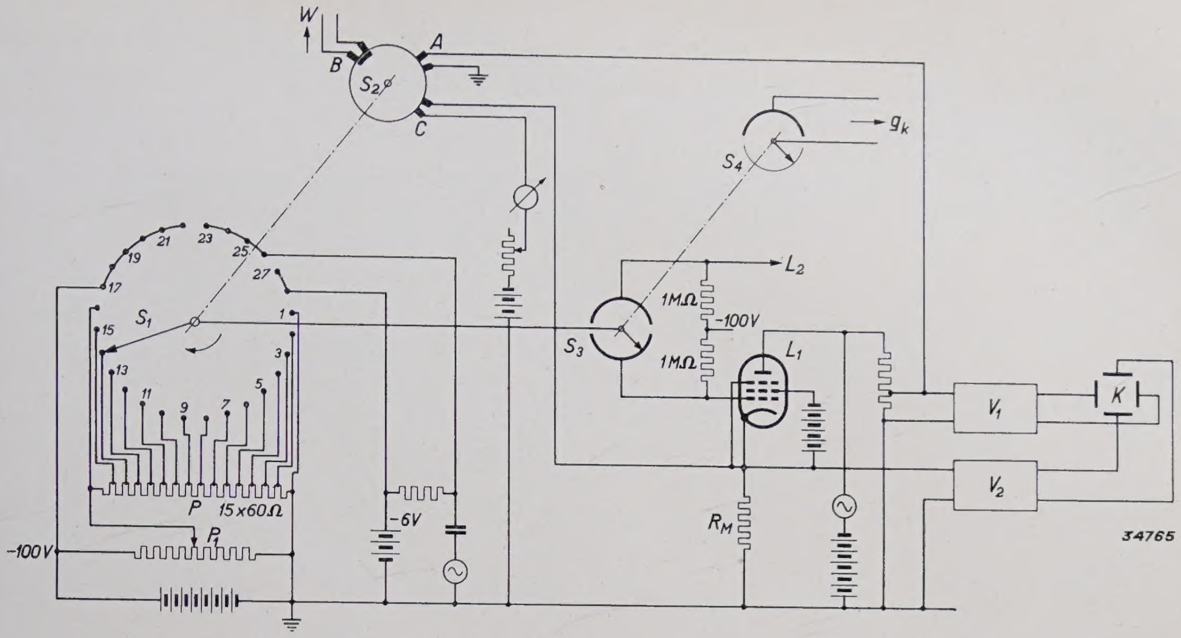

Fig. 3. The anode voltage of the output valve L_1 to be investigated is applied to the plates for horizontal deflection of the cathode ray tube K *via* the amplifier V_1; the voltage over the measuring resistance R_M, through which the anode current flows, is applied *via* the amplifier V_2 to the plates for vertical deflection. By means of the rotating switch S_1 the grid bias of the output valve is varied in steps. The auxiliary switch S_2 which is fastened to the axis of S_1 short circuits the pairs of brushes A, B, C at certain moments, and thus causes the various auxiliary lines of the diagram to be traced on the fluorescent screen. The switches S_3 and S_4 which rotate with half the velocity of S_1 serve to record the diagrams of two output valves L_1 and L_2 at the same time, while the voltage on the grid g_k of the cathode ray tube is lowered for the diagram of one of the valves. With the help of the potentiometer P_1 the current through the potentiometer P can be regulated and the grid bias stepwise variation can be made more or less steep.

contacts and the auxiliary switch S_r which is fastened to the axis of the rotating switch and passes over the pairs of brushes A, B, C (fig. 3) serve these purposes.

The horizontal axis is produced automatically due to the fact that during the currentless periods (contacts *17-22*) the fluorescent spot moving back and forth is not deflected in a vertical direction. The vertical axis is traced in the diagram when the switch passes over contacts *23* and *24*. At this moment the input of the amplifier for the voltage for horizontal deflection is short circuited *via* the brushes A. On the contacts *23* and *24*, which now feed the grid, an A.C. voltage now acts so that the anode current may vary sufficiently to describe the whole I_a axis. The same is true for the following two contacts, *25* and *26*. At the moment at which these contacts are connected to the grid, the second pair of brushes B brings about a substitution of the anode A.C. voltage by the normal anode D.C. voltage of 250 volts, for instance. The vertical line $V_a = 250$ volts is therefore now drawn in the diagram, which facilitates finding the operating point, and at the same time provides the scale for the horizontal axis. The scale for the vertical axis is obtained by passing a direct current of known magnitude through the measuring resistance R_m during the resting period of the valve (contacts *17* and *18*). This is done by means of the two brushes C, and gives in the diagram a horizontal line at a definite height above the V_a axis.

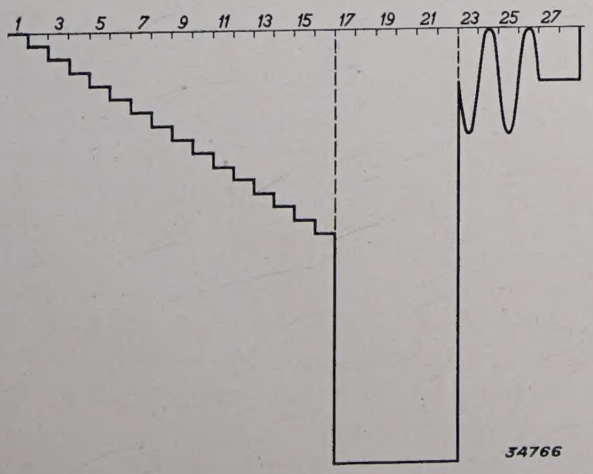

Fig. 4. The variation of the grid bias of the output valve under examination during one revolution of the rotating switch (S_1 in fig. 3).

The remaining two contacts *27* and *28* are at a negative voltage of a given magnitude, —6 volts for instance. The I_a-V_a curve with the parameter $V_g = -6$ volts is traced *via* these contacts. By regulating the potentiometer current and thus the voltage on the contacts *1* to *16*, one of the

15 I_a-V_a curves can be made to coincide with the established curve for $V_g = -6$ volts, and the parameter value for all the other curves is thus also known.

It is, however, seldom necessary, and with regard to clarity, it is sometimes even undesirable to record 15 I_a-V_a curves of the diagram. In that case the stepped voltage in fig. 4 is made so steep by increasing the potentiometer current, that on part of the contacts *1* to *16* the voltage is high enough to completely suppress the anode current of the output valve. The valve then has a longer resting period.

The comparison of two output valves

In addition to the rotating switch S_1 and the auxiliary switch S_2 there is a rotating contact S_3 which rotates at one half the speed of the first switch (fig. 3 and *fig. 5*). By means of this contact the grid bias according to fig. 4 may be applied alternately to two output valves. On the screen of the cathode ray tube the I_a-V_a diagrams of first one and then the other valve are drawn alternately, and since this takes place for each valve about 8 to 12 times per second, the two diagrams appear simultaneously on the screen. This makes it easy to detect quickly small differences between two valves of the same type. In order to be able to distinguish the two sets of curves from each other, the current of the cathode ray is diminished slightly with the help of the contact S_4 during the time when one of the valves is in circuit, so that the set of curves for this valve appears on the screen with a lower light intensity.

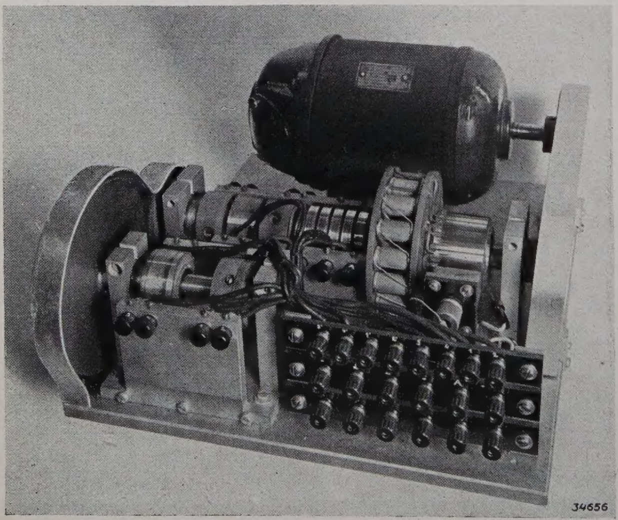

Fig. 5. The combination of rotating switches (S_1 to S_4 in fig. 3). For structural reasons, the switch arm of S_1 (a brush) is stationary while the 28 contacts (lamellae of a collector, middle axis on the right) rotate beneath it. The 15 resistances of the potentiometer P turn with the collector, the necessary voltages are applied *via* five slip rings. The auxiliary switch S_2, also for practical reasons, is divided into three contact makers (middle axis, left). The front axis turns at half speed and moves to two switches S_3 and S_4.

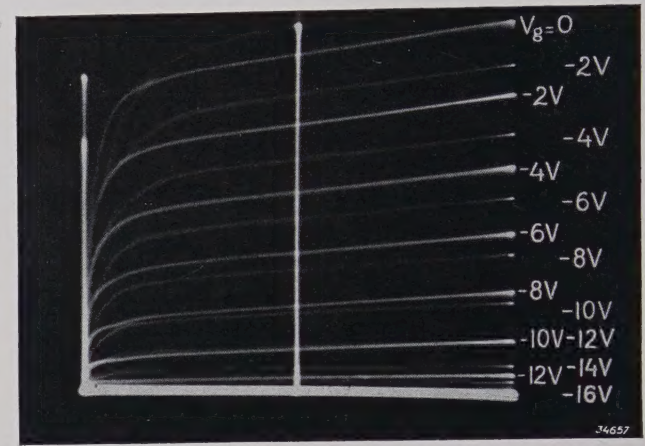

Fig. 6. Photograph of the I_a-V_a diagrams of two valves taken at the same time. One diagram is traced with lower intensity for the sake of distincion.

Fig. 6 gives an example of such an application of the apparatus. One valve (curves with lower intensity) has a smaller slope and a higher maximum anode current at $V_g = 0$ (highest curve). Furthermore the I_a-V_a curves of this valve do not run as close to the I_a axis as those of the other curve, a fact which has an unfavourable effect on the distortion at high values of the grid excitation current. Without going more deeply into this matter it may be noted that these deviations are caused by the fact that the cathode of this valve was not accurately centred with respect to the control grid.

Tracing the load line

When the I_a-V_a diagram has been photographed with a camera set up in front of the fluorescent screen, the load line may also be recorded on the same negative. For this purpose the output valve is first brought into the correct operating conditions, *i.e.* by means of suitable D.C. voltages on grid and anode the operating point is arrived at, and the loading impedance is put into the anode circuit *via* a transformer. If the anode current is now projected on the screen as a function of the anode voltage once more, the load line is obtained. There is however still a complication: without special precautions the load line is not in the correct position in the diagram. Ordinary amplifiers, such for example as those built into cathode ray oscillographs, do not pass D.C. voltages. When a voltage, whose mean value is not equal to zero, and which therefore has a certain D.C. component, is applied to the cathode ray tube, the image on the screen always adjusts itself so that this average value of the voltage lies at the centre of the screen. When such amplifiers are used, therefore, the I_a-V_a diagram is projected on the screen in such a way that the centre of the screen is the point of greatest density of all the values of voltage and current occurring. The same is true in the case of the load line. Actually, however, the centre of the load line must coincide with the operating point of the diagram, which means that amplifiers used for this purpose must not suppress the D.C. voltage component.

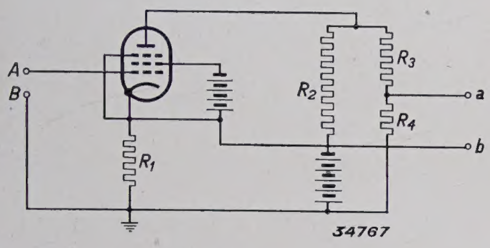

Fig. 7. First stage of the D.C. push-pull amplifiers for the deflection voltages. By giving the resistances R_1-R_4 suitable dimensions, upon application of an A.C. voltage to *AB*, the potential at *a* is made to increase by the same amount as that at *b* falls. The D.C. voltage potential at both points is adjusted to the same value by regulation of the anode direct current.

In order to obtain an accurately focussed image on the screen of the cathode ray tube, the potential in the middle of each set of deflection plates must remain constant (the focussing of the electron beam depends upon this). This means that the voltages must be applied to the deflection plates in a push-pull connection. One thus arrives at the somewhat unusual requirements of D.C. push-pull amplifiers.

Fig. 7 shows diagrammatically how the first stage of these amplifiers is arranged. The value of the resistance is for example the following: $R_3 = 18\,R_1$, $R_4 = 2\,R_1$, $R_2 = R_3 + R_4 = 20\,R_1$. If an A.C. voltage is applied to the input side *AB*, an A.C. voltage occurs over $R_3 + R_4$ which is ten times as great as that on R_1. The A.C. voltage over R_4 is thus equal to that over R_1, but in opposite phase. Since the potential of *a* at every moment rises as much as that of *b* falls, the tension between *a* and *b* is the desired push-pull voltage, provided *a* and *b* have the same D.C. voltage potential. This may be realized by regulation of the anode direct current, for instance by means of an adjustable resistance in series with the cathode, or by a suitable adjustment of the screen grid voltage. The further amplification of the symmetrical halves of the push-pull voltage is carried out in the manner usual for D.C. amplifiers. A diagram of the complete circuit is given in *fig. 8*. The points *a* and *b* correspond to the points *a* and *b* in fig. 7. It may be seen that in the practical application no special battery has been used for the screen grid. In addition to the anode current the screen grid current now also flows through the cathode resistance. Therefore the ratios between the resistances R_1 to R_4 (fig. 7) are slightly altered.

Fig. 9 is a photograph of the whole apparatus.

Load lines for different cases

In the simplest case in which the loading of the output valve consists of a pure resistance, the load line is a straight line through the operating point, as was indicated in fig. 1. *Fig. 10* is a photograph of such a case. The loading resistance in this case was equal to the so-called optimum resistance with which the output valve delivers the maximum power at a definite distortion (10% in this case). For output pentodes the optimum value is usually equal to the quotient of anode D.C. voltage and current. In that case the amplitudes of the anode A.C. voltage and current can simultaneously reach their maximum values, which are approximately equal to the anode D.C. voltage and current, respectively.

In practical cases the load on an output valve usually consists of one or more loud speakers. The

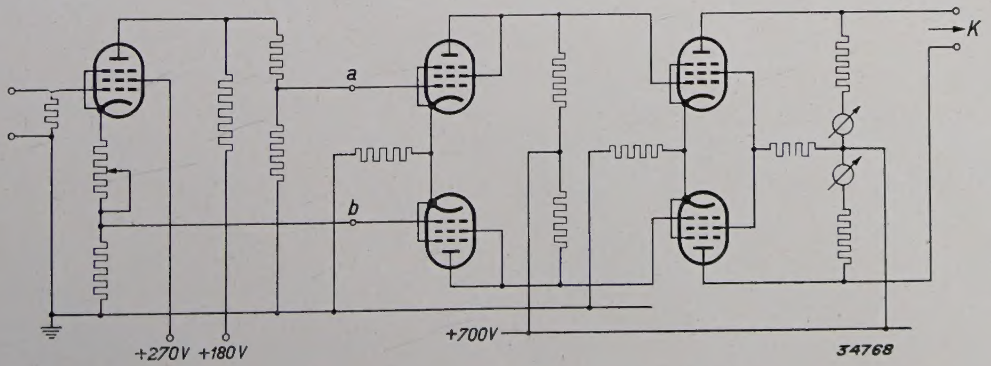

Fig. 8. Diagram of the complete circuit of the D.C. push-pull amplifiers *a* and *b* correspond to the points *a* and *b* in fig. 4.

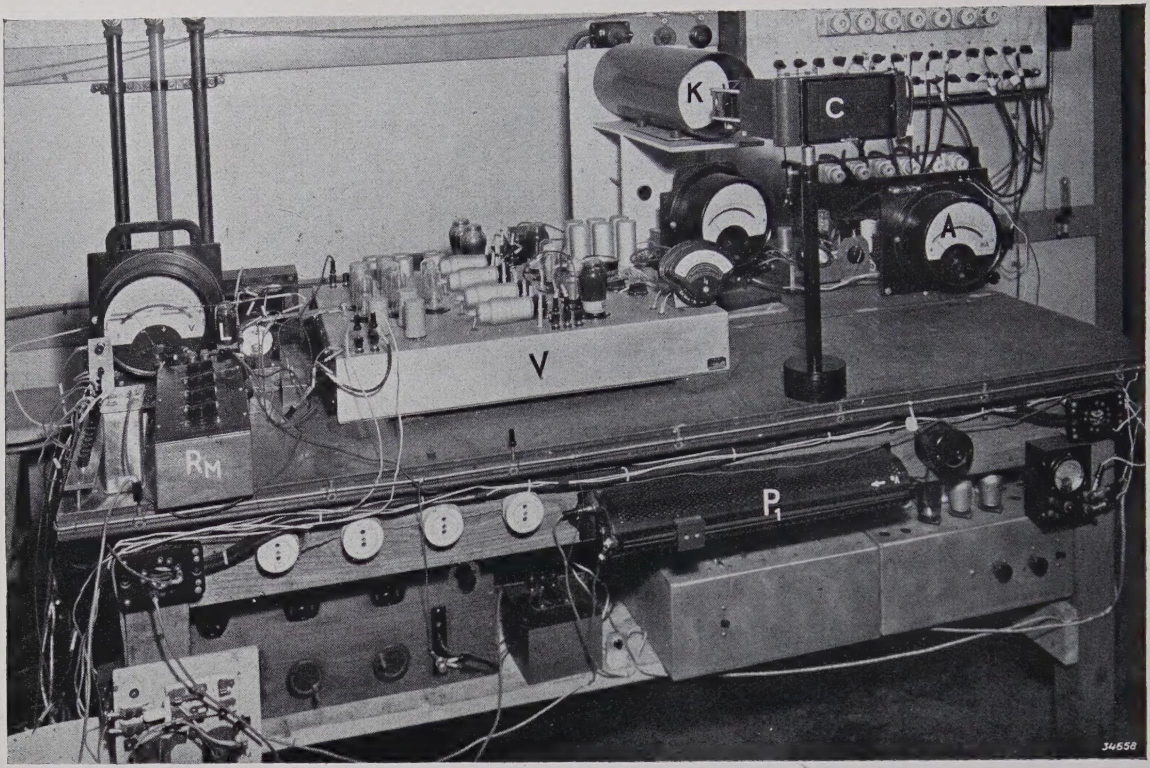

Fig. 9. View of the complete installation. L is the output valve under investigation, R_M the measuring resistance for the anode current, V the two amplifiers for the deflection voltages, K the cathode ray tube, C the camera set up in front of the screen. On the meter A the calibration current can be read off which is sent through the measuring resistance R_M during the resting period of the output valve (contacts *19-20* in fig. 4). With the potentiometer P_1, the steepness of the grid bias stepwise variation is regulated.

impedance of these is not a pure resistance but is inductive for a large part of the frequency range, due to the self-induction of the loud-speaker coil. The variation of the absolute value and the phase angle of the impedance of an ordinary loud speaker of good quality with appropriate transformer is represented in *fig. 11*. As a measure of the magnitude of the impedance the value at 1 000 c/sec is generally taken. In our case this amounts to about 7 000 ohms, which corresponds to the optimum resistance for the 9 watt pentode EL_3. The phase angle at the frequency mentioned is about 45°.

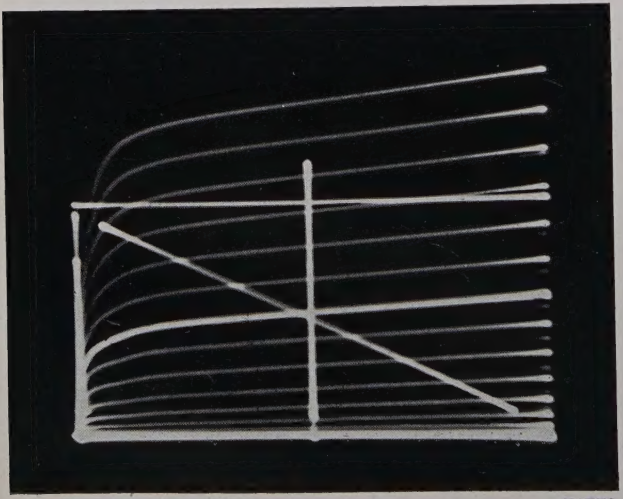

Fig. 10. Load line for the case in which the output valve is loaded with a pure resistance. The resistance here has the optimum value: the operating point lies in the middle of the section which is cut off on the straight load lines by the axes.

As a result of the phase shift between anode A.C. voltage and current a straight line is in general not obtained in the I_a-V_a diagram of the output valve. With a grid A.C. voltage of given frequency and amplitude, a more or less elliptical load line is obtained around the operating point. In *fig. 12* a number of such ellipses are shown which are obtained at different amplitudes of the grid A.C. voltage. If the grid A.C. voltage contains different frequencies more complicated figures occur. Examples are shown in *figs. 13* and *14* in which two frequencies, having the ratios 1 : 4 and 1 : 15, respectively, were applied to the grid, and in *fig. 15* in which three frequencies were combined. Finally, in *fig. 16* the image is given which is obtained when the output valve, loaded with a loud speaker, is allowed to amplify music for some time. One can no longer speak of a load line, but of a load field which occupies a more or less extensive portion of the I_a-V_a diagram.

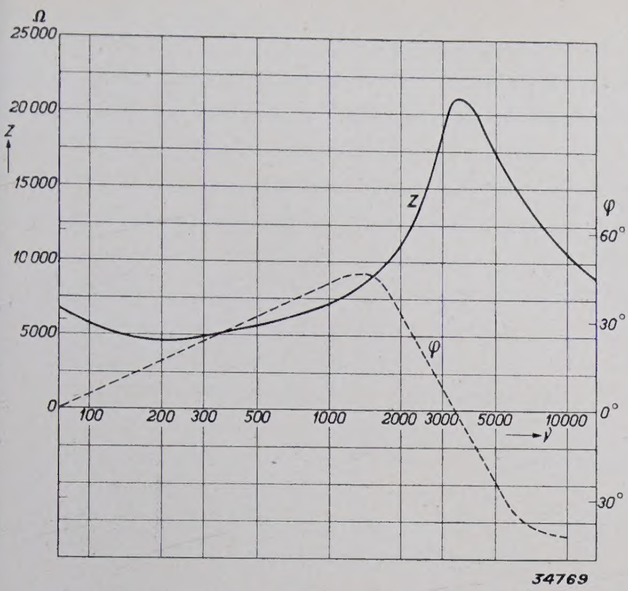

Fig. 11. Variation of the absolute value Z and the phase angle φ of the impedance of a normal loud speaker of good quality as a function of the frequency ν in c/sec. In this measurement a condenser of 2 000 μF was connected in parallel with the primary winding of the loud-speaker transformer, as is the case in many radio receivers. At 1 000 c/sec, $Z = 7\,000$ ohms. At lower frequencies Z changes only slightly: the minimum lies at 200 c/sec and amounts to about 5 000 ohms. At higher frequencies Z first increases sharply to about 21 000 ohms at 3 000 c/sec, it then decreases again due to the influence of the condenser. Cheaper types of loud speaker show in general a greater variation of Z and φ with the frequency.

The form of the I_a-V_a diagram

After an idea has been obtained in this way of the size of the region used in the I_a-V_a diagram, the requirements can be more precisely defined which the I_a-V_a diagram must satisfy in order to obtain as little distortion as possible in the reproduction and as large an output as possible.

Since the anode A.C. voltage and with it the output is limited by the crowding of the I_a-V_a curves near the vertical axis, it is desirable that the curves should run as closely as possible along the vertical axis at low anode voltages or in other words that in this region the anode current should increase very rapidly with the anode voltage. By the introduction of the screen grid it was possible to satisfy this requirement, without being compelled to use positive grid voltages, involving a consumption of energy by the grid as in triodes. At the same time, however, in the tetrode thus formed the phenomenon occurs that secondary electrons, formed at the anode, may pass to the screen grid, which causes a kink in the I_a-V_a curve (*fig. 17a*). In order to avoid these kinks which are accompanied by great distortion, a third grid (suppressor grid) is introduced, which is at cathode potential, and which suppresses the secondary emission from the anode to the screen grid. In the older types of pentodes, however, this sup-

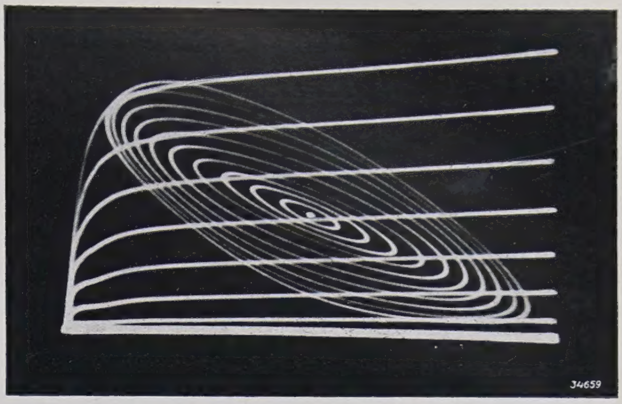

Fig. 12. With inductive loading of the output valve (connection to loud speakers) the load line becomes a more or less distorted ellipse around the operating point when the grid excitation voltage is sinusoidal. In this recording the amplitude of the grid excitation voltage was varied in steps with the frequency constant.

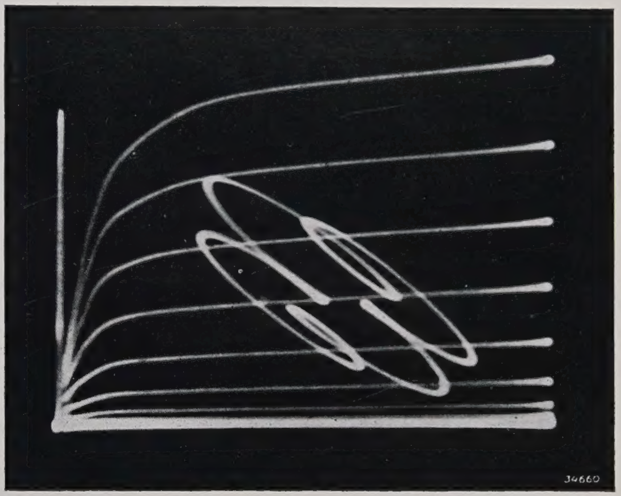

Fig. 13. Two A.C. voltages with a frequency ratio of 1 : 4 are applied to the grid of the inductively loaded output valve.

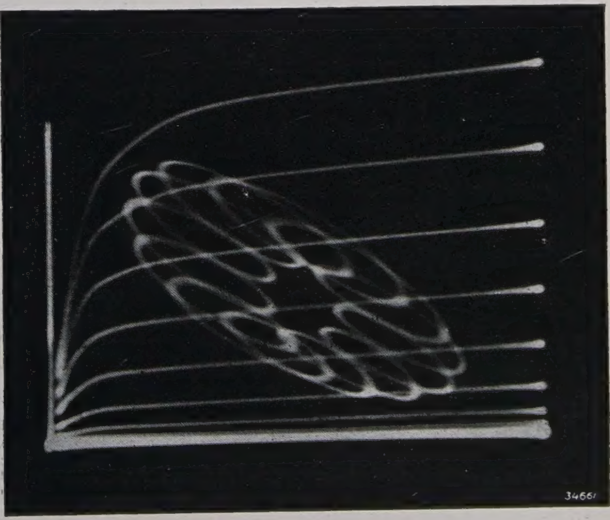

Fig. 14. Like fig. 13, but with a frequency ratio of 1 : 15.

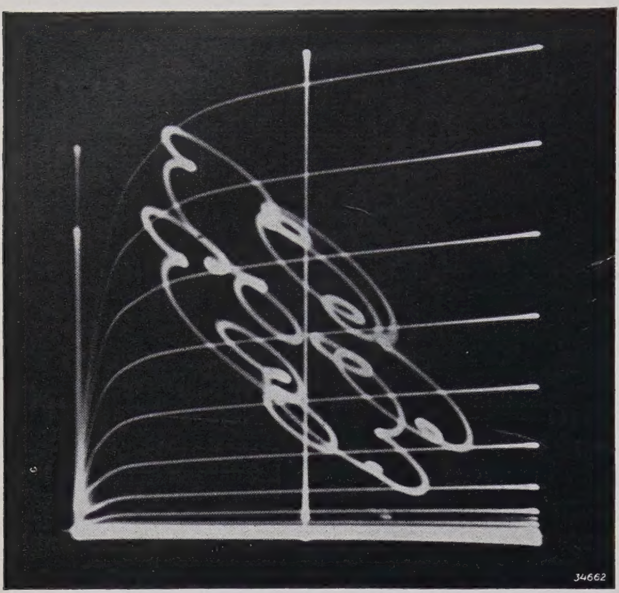

Fig. 15. Three frequencies are supplied to the grid.

pression was often so thorough that at low anode voltage part of the primary electrons emitted by the cathode were also forced to reverse their direction in front of the third grid. These electrons were then lost for the anode current, and the result was that the anode current increased less rapidly with the anode voltage.

By a correct choice of position and dimensions of the suppressor grid the decrease in power output which hereby occurs can be kept very small. In the work involved in this development the method described in this article for the recording of I_a-V_a diagrams has proved very useful. A change in position and dimensions of the suppressor grid is to a certain extent equivalent to a definite change in its potential. By applying different negative or positive voltages to the suppressor grid — which in contrast to the ordinary construction must have leads to the outside — and by inspecting the I_a-V_a diagram in each case, it is possible to discover the voltage at which the most favourable form of the diagram is obtained. *Fig. 17* shows three records from such an investigation. In *a* the kinks are very pronounced, in *b* they have entirely disappeared, but at the same time the anode current increases much more slowly with the anode voltage, in *c* the correct compromise has been found in which the curves mount as steeply as possible while the kinks are only present in a region of the diagram which, according to the investigation of the load field (see above), is not used in practical cases.

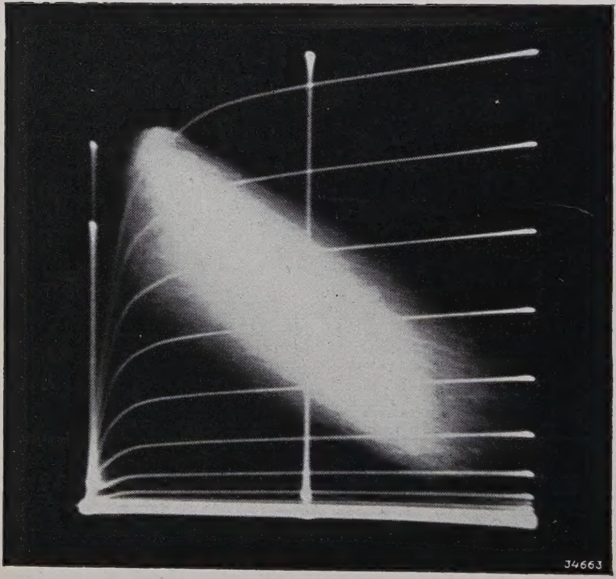

Fig. 16. The A.C. voltage of music is applied for some time to the grid of the output valve. A certain "load field" is now covered in the I_a-V_a diagram.

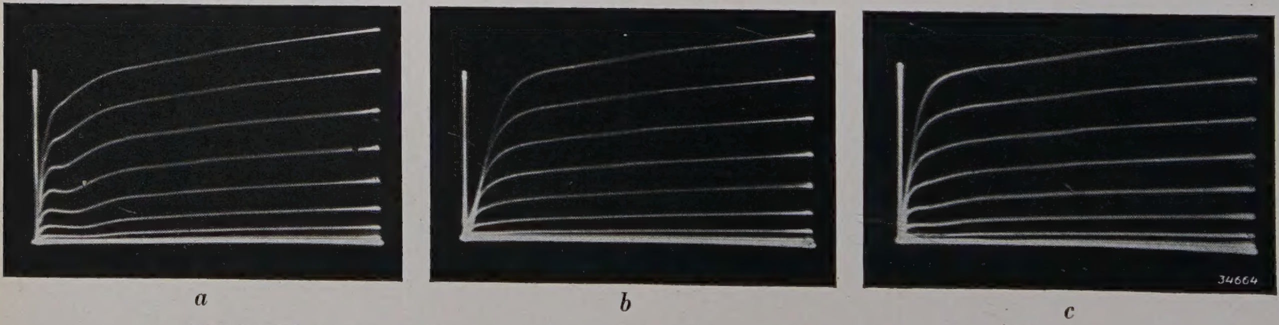

Fig. 17. The I_a-V_a diagram of a pentode at different potentials of the suppressor grid.

a) The suppressor grid is too strongly positive, the kinks in the characteristics due to secondary emission from the anode are not sufficiently suppressed.

b) The suppressor grid is too strongly negative. The kinks in the characteristic have disappeared, but at low anode voltages the curves rise less steeply.

c) The suppressor grid has the optimum potential. This value of the potential gives an indication of the sense in which position and dimensions of the grid must be changed in order to obtain the same result with this grid at cathode potential.

X-RAY APPARATUS FOR THE MACROSCOPIC EXAMINATION OF MATERIALS

by J. E. de GRAAF. 621.386.1 : 539.26

In the construction of X-ray apparatus to be used for the macroscopic examination of materials several problems occur which are connected with the use of high voltages and currents, such as the problem of the insulation of the apparatus and cables, and the dimensions of the focus of the X-ray tube. These problems are discussed in this article.

Introduction

Special X-ray apparatus have been constructed by Philips for the macroscopic examination of materials, a subject on which a series of articles has appeared in this periodical [1]). These apparatus are simple in operation and are not dangerous for the operator. In this article we shall discuss the factors which were taken into account in the construction of these apparatus.

The apparatus are intended for use in making X-ray photographs of a large number of articles which may have large dimensions. The economic factor of time-saving is of great importance. According as the examination is transferred more and more from the laboratory to the workshop, this consideration becomes steadily more significant. The time necessary to take a photograph may be divided into two parts, namely:

1) the exposure time proper, and

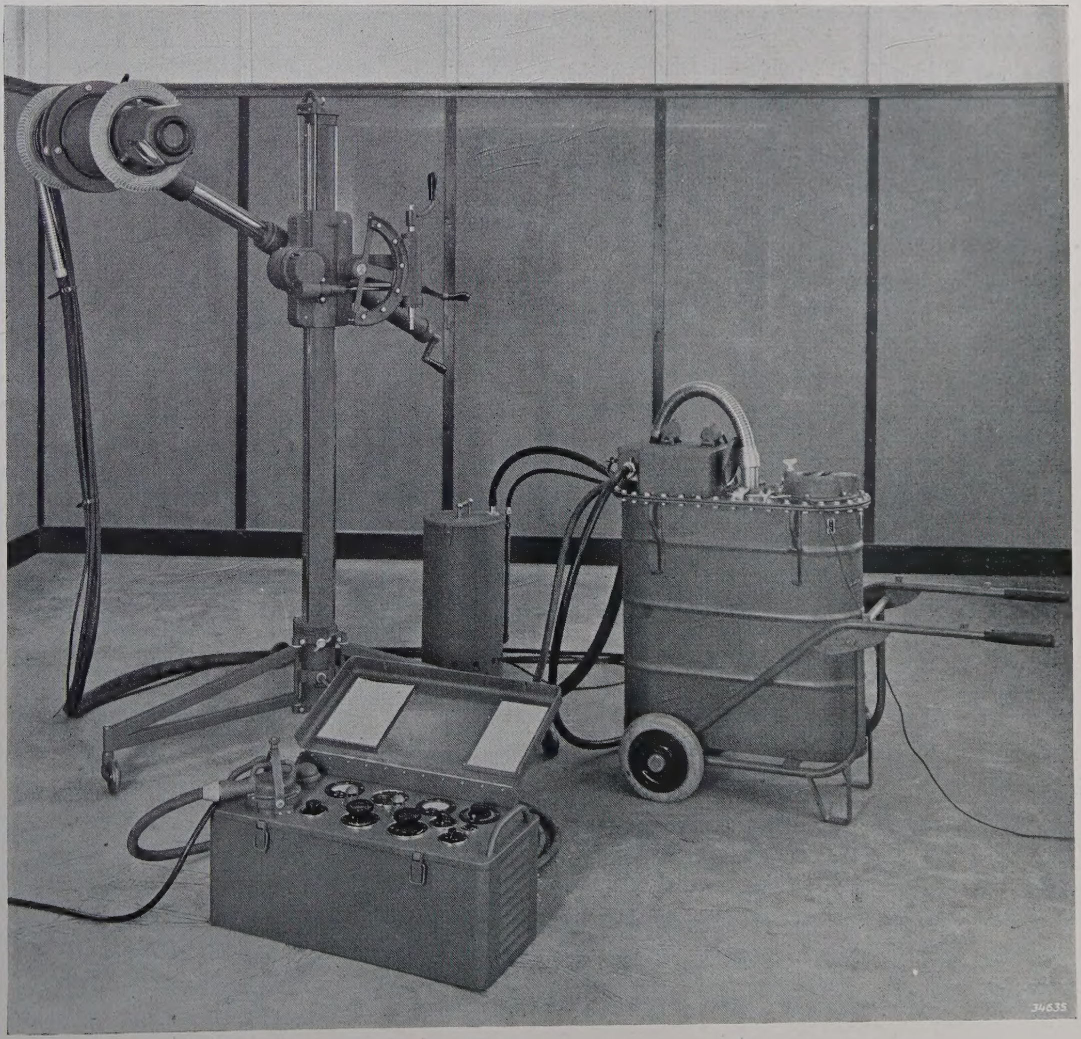

Fig. 1. The X-ray apparatus M 150 with earthed anode which is intended for a maximum voltage of 150 kV. By dividing it into components of small dimensions and light weight it has been made easily transportable. The connections are given in fig. 2.

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[1]) Philips techn. Rev. **2**, 314, 350, 377, 1937 en **3**, 92, 186, 1938.

2) the time necessary for moving about and adjusting the X-ray apparatus.

Consideration of the second item shows that it is desirable that the apparatus should be easy to handle. It should therefore be made as small and light as possible.

As for the necessity of keeping the exposure time itself short, this makes it necessary to use high tensions, even as high as several hundred kilovolts, especially in the examination of heavy pieces of work. With increasing voltage the exposure time needed for a given density on the film decreases very rapidly [2]). The problem is therefore reduced to that of obtaining as high voltages as possible with an apparatus which is easy to handle.

Since high-tension transformers and insulators are usually large and heavy, the X-ray apparatus for the purpose in view must immediately be divided into a number of components which can be transported separately, and each of which can easily be handled. The X-ray tube itself is suspended in a convenient support, as may be seen in *fig. 1*. The most difficult problem is that of the high-tension generator which always remains a heavy unit.

By means of special connections it is possible to obtain on the X-ray tube twice the voltage of the high-tension transformer, so that a much smaller transformer may be used to obtain a given voltage. In *fig. 2* a circuit is given which has previously been discussed in this periodical [3]). It employs for this purpose a rectifier valve V which is connected in parallel with the X-ray tube R. During the phase in which the rectifier valve has only a small resistance the buffer condenser C is charged to the peak voltage of the transformer T, since then practically no voltage acts on rectifier valve and X-ray tube. During the opposite phase this voltage on the condenser acts in series with the voltage of the transformer, so that about double the peak voltage of the transformer acts between the terminals of X-ray tube and rectifier valve. The voltage on the X-ray tube is always equal to the sum of the A.C. voltage on the transformer and a D.C. voltage equal to the peak value of this transformer voltage. A voltage equal to twice the transformer voltage thus occurs on the tube in the circuit according to fig. 2 only during short moments, so that the use of this circuit by no means gives the same X-radiation for a given power as would be obtained upon the use of a transformer with twice the peak voltage.

In order to obtain a practically constant voltage on the X-ray tube, which shall be approximately equal to twice the transformer voltage, use may be made of the connections shown in *fig. 3*, in which two condensers and two rectifier valves are used.

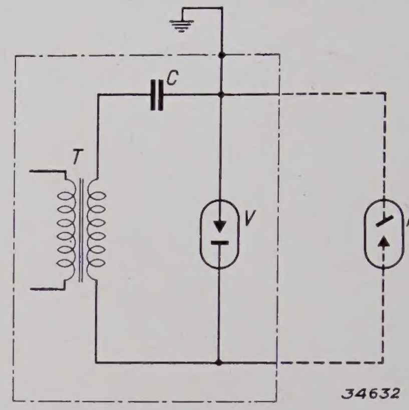

Fig. 2. Diagram of the connections, which supply to the X-ray tube R a pulsating voltage whose peak value is about double the peak voltage of the transformer T. C buffer condenser. V rectifier valve.

The condenser C_1 and the rectifier valve V_1 have exactly the same functions as in the circuit of fig. 2. At the moments when V_1 carries twice the peak voltage of the transformer, the rectifier valve V_2 connected counter to V_1 has a low resistance, so that the condenser C_2 can be quickly charged through V_2 to twice the peak voltage. Since the rectifier valves are connected counter to each other, condenser C_2 can only be discharged over the X-ray tube R, which has a resistance such that this discharge takes place only slowly, and the X-ray tube in this connection thus receives a practically constant voltage which is only slightly less than twice the transformer voltage.

As we shall see later, the apparatus are constructed according to the connections of fig. 2, and may be completed to give those of fig. 3 by means of a suitable auxiliary apparatus, which contains the condenser C_2 and the rectifier valve V_2.

As already mentioned, the density obtained on the

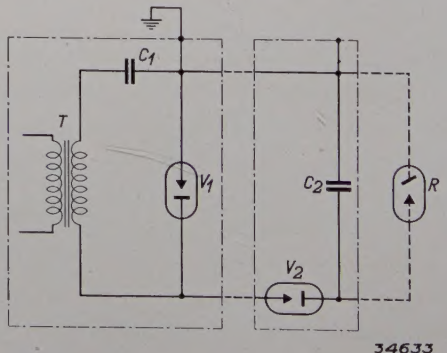

Fig. 3. Diagram of connections for obtaining a fairly constant voltage. C_1 and V_1 correspond to C en V in fig. 2. Another rectifier V_2 and a condenser C_2 have been added.

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[2]) *Cf.*: fig. 5 in Philips techn. Rev. **2**, 314, 1937.

[3]) Philips techn. Rev. **1**, 6, 1936.

photographic plate increases very rapidly with the voltage on the tube. Since with the circuit according to fig. 3, the voltage is never far below its maximum value, with the same average tube current, the same density may be obtained with a much shorter exposure time than is the case when the circuit of fig. 2 is used. *Fig. 4* shows how the X-radiation acting on the photographic film depends upon the thickness of the article examined. The X-radiation is expressed in terms of röntgen [4]) per minute per mA, measured at a distance of 1 m from the focus. The thickness is indicated by the equivalent thickness of copper in mm. It may be seen in the figure that at great copper thickness the circuit of fig. 3 is about 3 times as efficient as that of fig. 2 in the case of our apparatus.

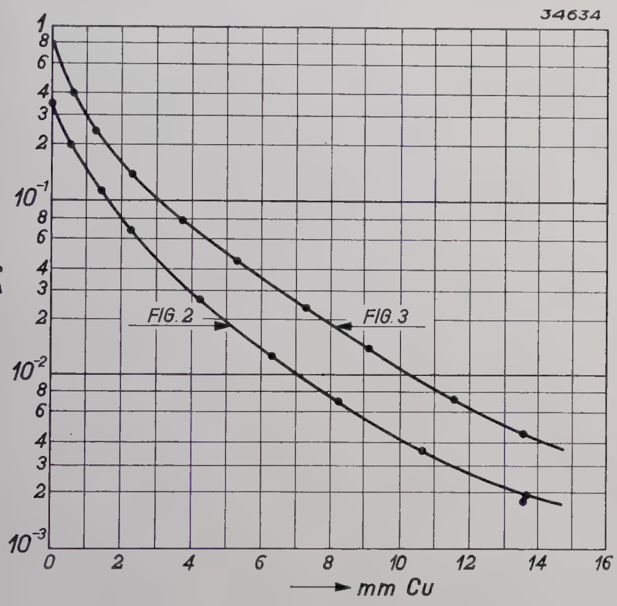

Fig. 4. For apparatus with connections according to fig. 2 and fig. 3 respectively, the amount of X-radiation acting on the photographic plate has been plotted. This is expressed in röntgen [4]) per minute per mA, and measured at a distance of 1 m from the focus through different thicknesses of the object examined, expressed in mm copper thickness. With large filter thicknesses the advantage of the circuit of fig. 3 over that of fig. 2 approaches a factor 3.

The insulation

In order to save weight in the construction of X-ray apparatus for testing materials, it is important to keep the relatively great weight of the insulation small. It would therefore seem advisable to use air as insulating medium as far as possible. Due, however, to the relatively low breakdown voltage of air such large dimensions would have to be used that the apparatus would become unwieldy, and unsuitable for use in limited spaces.

Since solid insulation materials have much higher breakdown voltages, much more compact designs can be arrived at with their use. Great care must, however, be taken that no air bubbles occur. either in the solid insulation itself or between the insulation and the parts insulated. The dielectric constant of air is smaller than that of all other dielectrics, so that the electric field in such air bubbles is greater than in the surrounding insulator. The danger thus arises that the gas in the bubbles will be ionized causing a discharge, corrosion and finally breakdown of the solid insulator [5]).

When it is only a question of simple constructions of porcelain, pertinax or "Philite", or, for example, of the rubber insulation of flexible high-tension connections, the occurrence of air bubbles can be avoided. With more complicated constructions, however, it is better to use a liquid insulation material, mineral oil for example. At the same time we insulate with this material the different parts of the generator not only with respect to each other but also with respect to the metal covering, which completely surrounds every part of a modern X-ray apparatus, and which is earthed in order to make it impossible for the operator to come into contact with any part under tension.

When mineral oil is used as insulation material it is possible that dust particles floating in it collect at spots with a high field strength and thus give rise to breakdown. Especially is this true if the dust particles contain moisture. Therefore care is taken by careful purification strictly to limit the number of dust particles and accompanying moisture, while care must also be taken that no impurities can enter the oil while it is in use. In this connection in our apparatus the space containing oil for the rectifiers, which must be accessible to the operator, is separated from that for the transformers and condensers. Furthermore by careful impregnation in a vacuum the air bubbles are driven out of the insulation.

In determining the required thickness of the layers of insulation, account must not only be taken of the difference of potential applied, but also of the nature of the surface of the conductors, which is an important factor. Irregularities, sharp angles and edges on a piece of metal to be insulated may cause unusually high fields in their neighbourhood. A simple example of an irregularity is the case of a hemisphere situated on one of two parallel planes and having a radius which is small compared with the distance between the planes. Such a hemisphere increases the field locally to about three times the field which would exist between the two parallel plates in the absence of the hemisphere. Care is therefore taken in the construction of the apparatus to give the conductors smooth flowing surfaces.

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[4]) An object receives an X-ray dosage of 1 r when 100 ergs would be absorbed in 1 cc of water at that spot as a result of the radiation.

[5]) *Cf.* the more elaborate treatment of this problem in the article, Pressure condensers, Philips techn. Rev. 4 254, 1939.

If the voltages are not too high, it is advisable to earth the anode of the X-ray tube, and supply the cathode by means of a high-tension cable. The focus lies at the earthed anode end of the tube, so that it is possible to introduce it relatively easily into small spaces. When for example it is necessary to project X-rays along the joining surface of two plates welded together at an angle, in order to discover faults in the joint, this can easily be done with a tube which has its focus at the end of the tube. An additional advantage of the earthed anode is that the heat developed at the focus, which amounts to about 2 kW with these tubes, can easily be dissipated by cooling water taken directly from the water mains.

A model of such a tube with earthed anode is shown in fig. 1. This tube can be used with voltages up to 150 kV. The connections of the apparatus are according to fig. 2. As already mentioned, by placing an auxiliary apparatus, in which condenser C_2 and rectifier valve V_2 are contained, between the tube and the supply apparatus of fig. 1, a unit is obtained with connections according to fig. 3, which can be moved about without much difficulty.

In the construction of such moveable apparatus it becomes difficult to insulate voltages higher than 150 kV with respect to earth. For such cases therefore a symmetrical construction has been employed as shown in *fig. 5* for a maximum tube voltage of 300 kV. In this case the focus lies at the middle of the tube; both cathode and anode are given opposite voltages of 150 kV with respect to earth by means of a high-tension cable. Since the focus is here not earthed, the anode is cooled by means of insulation oil which circulates through the anode and a cooler.

Since the voltages of cathode and anode are equal and opposite with respect to earth in a symmetrical tube, the electrical supply takes place with the help of two apparatus connected according to fig. 2, one of which is connected to the anode, while the other by reversing the rectifier supplies the reversed voltage to the cathode. Moreover, by adding two of the auxiliary apparatus mentioned above, one obtains the circuit of fig. 3 doubled, which gives a constant voltage between anode and cathode.

The focus

If we attempt to shorten the exposure time by using higher voltages, as was explained in the foregoing, the X-rays obtained are harder. As has previously been explained in this periodical [6]) this

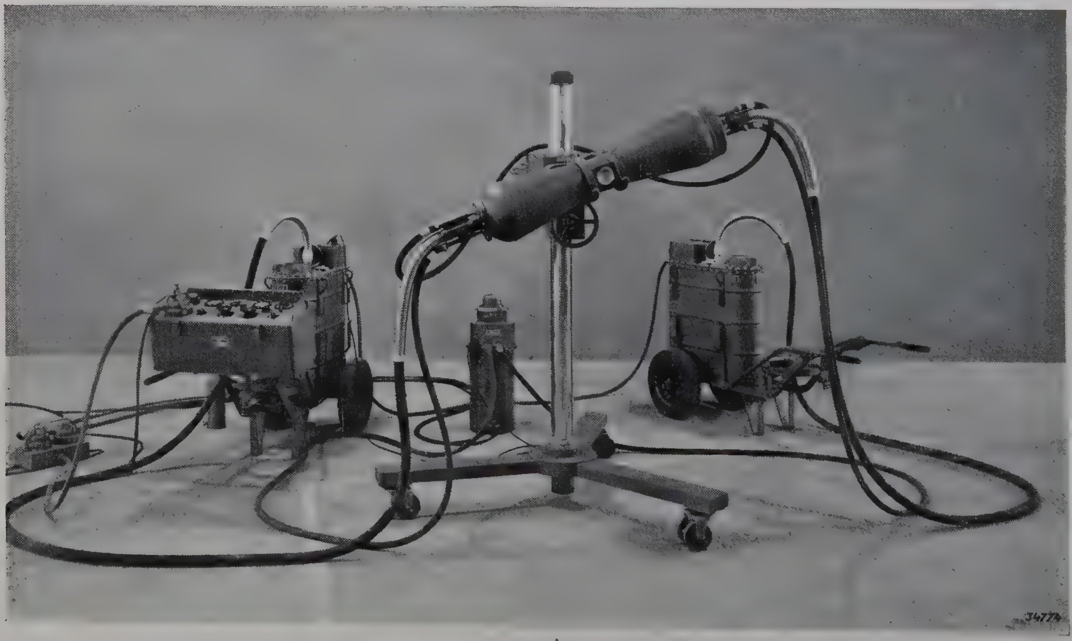

Fig. 5. The X-ray apparatus M 300 with symmetrical X-ray tube, supplied by two high-tension cables. It is designed for a maximum voltage of 300 kV. The generator is a symmetrical combination of two generators of the type M 150.

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[6]) *Cf.*: fig. 6 in Philips techn. Rev. **2**, 314, 1937.

meets with the objection that the X-ray photographs will exhibit less contrast than when they are made with softer X-rays. In addition to raising the voltage, therefore, some other possibilities of increasing the X-ray intensity is desirable, such for example as the application of a high average tube current.

A high current can be obtained either by procuring a high current density or a large cross section area of the current. The first of these methods means a high specific loading of the focus, and it has already been explained in this periodical 7) that this cannot be carried too far. The heat produced at the anode cannot otherwise be dissipated sufficiently well. The temperature of the anode might become so high that the anode would become rough due to evaporation, which could cause the efficiency of the tube to decrease too rapidly during operation. In the article cited it is also shown how it is possible to obtain the greatest permissible specific loading of the focus.

The second method of increasing the tube current is to increase the size of the focus. This method also has its limits since the lack of sharpness of the shadow image of the X-rays is proportional to the dimensions of the focus. If this lack of sharpness is not greater than the dimensions of the faults which one is desirous of discovering in the structure examined it is permissible. Depending on the nature of the object in view, therefore, there are corresponding optimum dimensions of the focus, which in turn correspond to a definite tube current.

For many uses of the tube shown in fig. 1 it is best to use a current source about 5 mm square with which a loading of 20 mA at 150 kV is possible with connections according to fig. 2. If it is necessary to introduce the focus into a small space, as is the case for instance in the examination of welds in steam boilers and pipes, the tube shown in *fig. 6* is very useful. In this tube the anode is situated at the end of a rodlike projection which is easily inserted into small spaces. Because of the small distance between focus and object in this case the dimensions of the focus must not be too large. In the tube shown in fig. 6 the focus is 2 × 3 mm.

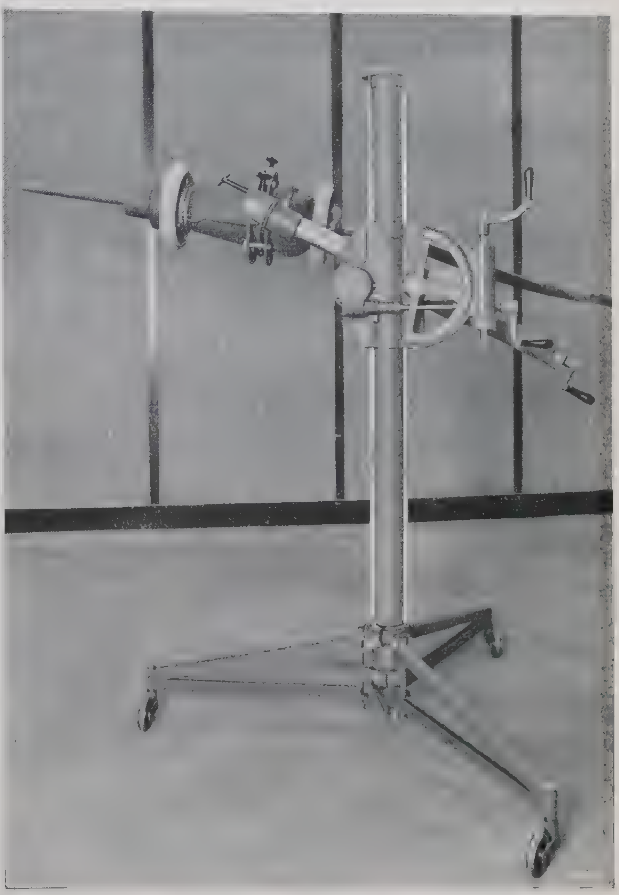

Fig. 6. X-ray tube with earthed rod-shaped anode designed for a maximum voltage of 150 kV. The focus lies at one end of the long projection.

The desired dimensions of the focus are in general obtained by applying a cap of a certain shape around the cathode, as may be seen in the construction diagram *fig. 7* of the tube of fig. 1. The cap *D* has such a shape that the electrons emitted by the cathode *K* are directed in a beam on to the anode *A*. Depending on the shape of the cap a larger or small-

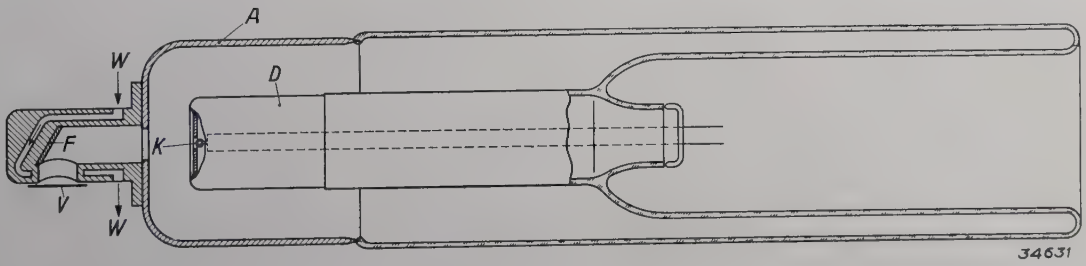

Fig. 7. Diagram of the structure of the X-ray tube belonging to the apparatus M 150 shown in fig. 1. The anode *A* is earthed and water-cooled. *F* focus, *K* cathode, *D* cap around cathode, *V* window and *W* cooling water.

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7) Philips techn. Rev. **3**, 259. 1938.

er electron optical image of the cathode is formed on the anode. As may be seen in fig. 7 this focus *F* which emits the X-rays is situated in a short projection of the chrome-iron anode cylinder *A* to which the glass is fused which serves as insulation between anode and cathode. In the tube with projecting anode shown in fig. 6, however, the focus is too far away from the cathode for a cap *D* to be used to form a beam of electrons which is satisfactorily parallel. The beam in this case must be made to converge by means of a magnetic field [8]), for which purpose a magnet coil is applied around the anode cylinder.

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[8]) *Cf.* Philips techn. Rev. 4, 153, 1939. In the tube for 1 MV there discussed a permanent magnet was used for focussing.

THE TRANSPORT OF SOUND FILM IN APPARATUS FOR RECORDING AND REPRODUCTION

by J. J. C. HARDENBERG. 778.533.1: 681.84.081

In order to avoid disturbing distortion in the reproduction of sound film, the film must be moved very uniformly past the spot where recording and scanning of the sound track takes place. In the combination of picture with sound track, in order to obtain a stationary picture the number of pictures per revolution of the driving mechanism is fixed, and therefore the velocity of the film is subjected to variations due to the shrinkage of the film material. The difficulties hereby ensuing for the transport of the film are discussed in this article, as well as several methods and types of constructions by which the problem is solved in modern machines for recording and reproducing sound film. In the Philips-Miller system of sound recording on the one hand more rigorous demands are made on the arrangement for film transport, and on the other hand for certain important applications the requirement of synchronization with the picture no longer holds, so that the construction may be considerably simplified. Several important structural details of the machines for the Philips-Miller system are described.

Sound recording involves the conversion of the temporal variations of the sound pressure into spatial variations of some physical quantity, such as the intensity or the width of an opacity along a band of film. In the reproduction, the spatial differences are reconverted into temporal differences. In order to ensure absolute similarity between the sound vibrations reproduced and those recorded the relation between "time" and "place on the band of film" must obviously be exactly the same in the recording and in the reproduction. In practice this means that high requirements must be made on the uniformity with which the film is transported in the machines for recording and reproduction, and on the stability (freedom from vibrations) of the spot where the recording or scanning of the sound track occurs. Every shortcoming in these respects is manifested as an undesired modulation and will make itself felt more or less audibly in the quality of the sound reproduced.

In satisfying the requirement mentioned certain difficulties occur which we shall discuss in the following. At the same time we shall describe several solutions to this main problem of sound film apparatus which have been proposed, and in particular the type of construction used in the machines for sound recording by the Philips-Miller system.

The sprocket roller

Sound film was originally developed as a supplement to the cinema film, and this is still its most important sphere of application. The transport of cinema film through the camera or projector always takes place by means of sprocket rollers, which catch in the perforations or sprocket-holes along both sides of the film. This method of transport makes it possible to draw the film past the projection window intermittently by means of the "Maltese cross" shutter — we shall confine ourselves to reproduction for the moment — and in this way give the audience the impression of a stationary picture. It is also possible, due to a so-called optical compensation, to draw the film past the film window at a uniform speed. Nevertheless the sprocket roller has persisted. The chief reason for this fact lies in the shrinking of the film which always occurs to some extent due to the drying out of the film especially by the strong illumination in projection. The shortening due to shrinkage may amount to 0.5 per cent, and in extreme cases to 1 per cent. In spite of this change in length it is now required that the film shall move a distance exactly equal to the height of one frame each time the picture changes. If the change occurs a given number of times per revolution of the axis which drives the Maltese cross at a given velocity, then, because of the shrinkage, the same number of metres of film per second is not always transported. The same number of sprocket holes per second however is maintained. The sprocket roller now serves to determine this number of sprocket-holes transported, and in this way to ensure precise picture transport. If differences in the height of the frames have occurred due to shrinkage they are corrected whenever a sprocket engages a perforation. In *fig. 1* the manner is shown in which this correction takes place. It may be seen that the film experiences a slight shock at each sprocket-hole. Since the film is normally projected with a speed of about 24 frames per second, and the height of a frame is equal to 4 sprocket-holes, the film undergoes about 96 shocks per second.

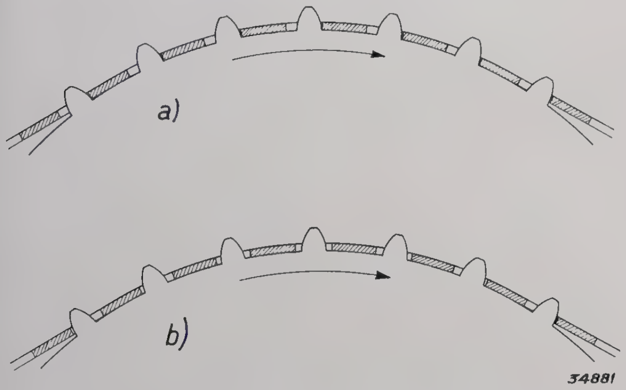

Fig. 1. a) If the distance between the film perforations corresponds to the thrust of the sprocket on the roller, the film rests against the flank of all the sprockets (10 for instance) which are engaged at the same time, and the transport of the film is taken over continuously by the sprockets which successively become engaged.

b) If the film is slightly shrunken, then, if we disregard the friction on the surface of the roller, it is only pulled along by the foremost sprocket, while the other engaged sprockets are loose in the perforations (the size of the perforations allows a play of about $^1/_2$ mm). At the moment when the foremost sprocket slides out of the perforation, the transport of the film has not yet been taken over by the following sprocket. The film thus decreases its speed relative to the roller for an instant until with a certain shock the following sprocket touches the edge of the perforation in which it previously stood free. This is repeated for each sprocket.

On the film intended for reproduction the sound track is added next to the pictures (*fig. 2*). If the film is more or less shrunk and if, after passing the projection window, it is drawn past the spot where the sound track is scanned by means of a sprocket roller, the 96 discontinuities per second which occur in the film transport due to the corrective action of the sprocket roller become noticeable as so-called sprocket-hole modulation in the sound

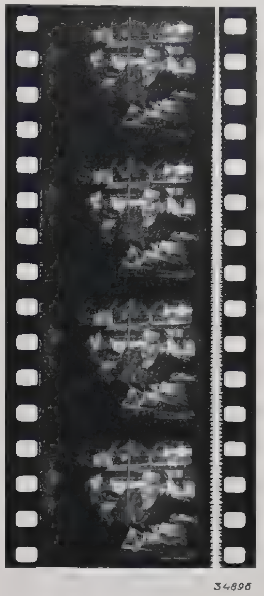

Fig. 2. Strip of film with pictures and sound track (recorded with amplitude modulation). The height of a frame corresponds to three sprocket-holes.

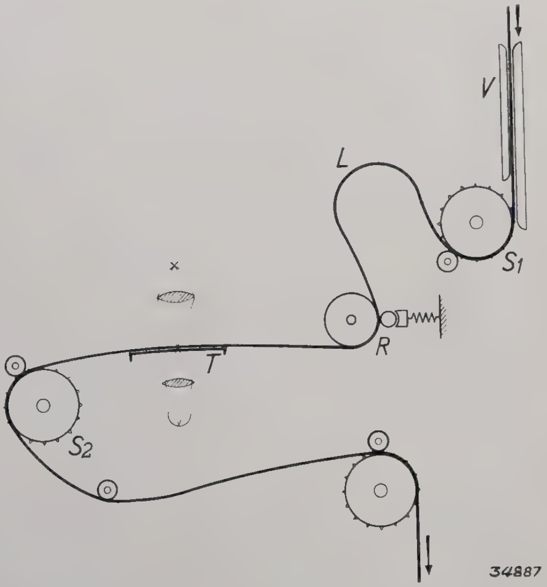

Fig. 3. After the film has been drawn intermittently by the sprocket roller S_1 on the shaft of the Maltese cross shutter past the projection window V, it is retarded by the rollers R (the loose loop L may periodically change its length unhindered upon change of picture). The sprocket roller S_2 then draws the stretched film through the gate T where the sound is scanned. Between V and T there is usually a length of film corresponding to about 19 frames. Picture and corresponding sound are thus relatively displaced by that amount on the film.

reproduction. In the initial stages of the development of sound film this was one of the most serious defects. The film was then always pulled by a sprocket roller S_2 in *fig. 3*, along a fixed gate where the sound was scanned, and it was retarded by the retarding rollers (R) in order to make sure that the film was firmly pressed into the gate. Due to the tension of the film between the gate and the sprocket roller pulling it, all the shocks were transmitted to the spot where the scanning took place. The reproduction of the frequencies between 2 000 and 6 000 c/sec were especially affected by the sprocket-hole modulation, since the combination tones occurring here give the impression of an unpleasant harshness.

A remedy was sought by damping the shocks of the sprockets by means of mechanical filters. Such a filter may for example consist of an elastic coupling between the sprocket roller and the axis driving it, or of a number of slack loops made in the film by stretching it around a series of guiding rollers between the sprocket roller and the spot where it is scanned. Fairly complex constructions are attained in this way and no decisive improvement is obtained.

The sound shaft

Considerable progress was made possible by the discovery of the fact, that as far as the sound is concerned it is not actually necessary to correct the variations in height of frame immediately, *i.e.* at every sprocket-hole. Care must only be taken that the length of film which passes the spot where the sound is scanned retains the same average value, over a period of a few seconds, as the length of the strip of film which passes the projection window, since otherwise either the film would break or become jammed. At the spot where the sound is scanned the film may be given a uniform velocity which only need correspond to the average length of film per picture in the course of several seconds, *i.e.* with inaudible "modulation frequency" [1].

This idea is realized in the following way. At or very near the spot where the sound is scanned the film is laid over a smooth drum touching the surface over as great a length as possible (*fig. 4*). The drum is mounted on a shaft which rotates very uniformly, called the "sound shaft" or "tone shaft". The uniform velocity of the shaft is guaranteed by a fly-wheel. A braking mechanism or a pressure roller at the side where the film runs on to the drums provides high peripheral friction so that the film is coupled with the surface of the drum and no slipping takes place. The film thus has the desired uniform velocity at this point. It is obvious that the sound shaft must be perfectly centred in order that the circumference of the drum may have a constant velocity. An excentricity of the drum of 0.02 mm would be clearly audible in the sound.

As is clear from the above no definite number of revolutions may be forced upon the sound shaft, but it must be allowed to adapt its velocity of rotation to the length of film reeled off. This can be done in two ways.

a) By means of an adjustable mechanical drive. As regulator device a loopsetter roller may here be used which keeps the film slightly stretched between the sound axis and a sprocket roller further along which runs synchronously with the pictures on the film. When a change in picture height occurs the paths covered by the film on the sprocket roller and the sound shaft exhibit a difference, the loop of film between the two spots becomes longer or shorter, the loopsetter roller changes its position and thereby influences in one way or another the driving speed of the sound shaft.

b) The latest solution of the problem consists in allowing the sound shaft to be driven by the

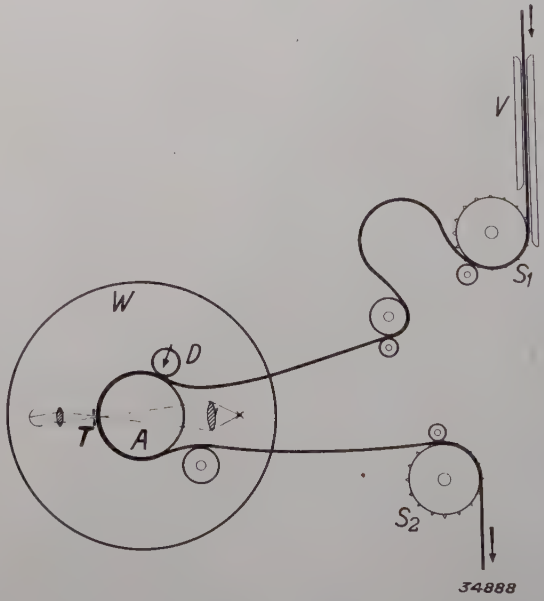

Fig. 4. The film is laid around the sound shaft A over a large angle. A rotates very constantly due to the action of the flywheel W. The pressure roller D, or some kind of braking arrangement, provides the necessary friction to prevent slip between sound shaft and film. The same symbols are used as in fig. 3.

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[1] Practically this average value varies so gradually, even with very irregular shrinkage of the film, that there are no noticeable deviations from synchronism between picture and sound.

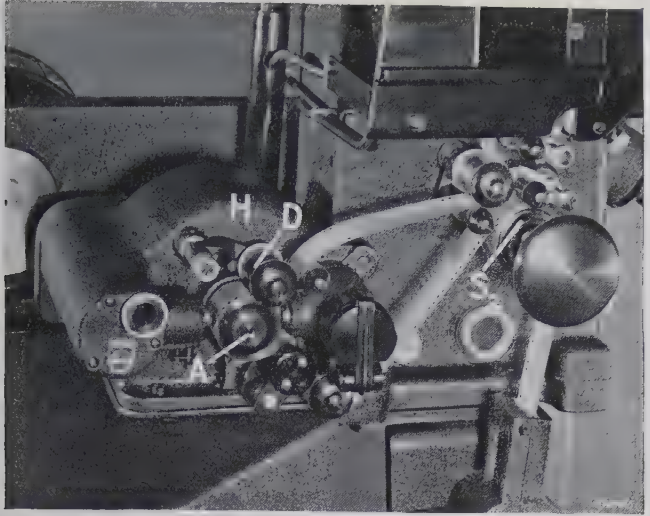

Fig. 5. Philips "sound head" type 3837 in combination with the projector FP 5. *A* is the sound shaft, *H* the housing of the fly-wheel, *D* the pressure roller, S_2 the sprocket roller which pulls the film through the sound head.

film itself. The film is fed to and reeled off from the sound shaft by sprocket rollers running synchronously with the pictures. The length of film reeled off is thus continually regulated by these rollers. The action of the freely running fly-wheel provides that variations in the film length per second cause gradual variations in the film speed on the sound shaft. It is however necessary that the coupling between the motion of the fly-wheel and the motion of the sprocket roller which pulls the film should be as loose as possible, *i.e.* that the strip of film between roller and sound shaft should be under as little tension as possible.

Of the above mentioned two possibilities of obtaining the necessary rolling friction a pressure roller or a braking arrangement, the first is to be preferred because it involves no extra tension on the film. In the new Philips "sound head" type 3837 (*fig. 5*) this method has therefore been used. The tension on the film is now determined practically only by the tension which the film must exert in order to overcome the frictional resistances which occur in the bearings of the sound shaft, the guiding rollers and the pressure roller. By the use of ball bearings it has been found possible in the case in question to reduce the frictional forces and thereby the pull on the film during reproduction to several tenths of a gram.

When reproduction is begun and the sound shaft must be set in motion by the film, the film must always exert a greater pulling force. Slipping hereby occurs during several seconds, either between sound shaft and film or between sound shaft and fly-wheel, if the latter is driven by the sound shaft *via* a friction coupling. The period before the operating state is reached depends upon the force which the film can transmit without danger of breaking, and on the energy which must be accumulated in the fly-wheel, *i.e.* at the moment of inertia of the latter.

Recording by the Philips-Miller system

In recording sound film the same construction may be used for the transport of the film as has been described above for the reproduction[2]). In general it is in this case even easier to keep the sprocket-hole modulation out of the sound, since one works with fresh film in which the distances between perforations are still relatively little changed by shrinkage, and with which therefore sprocket-hole shocks during transport occur to a much smaller extent.

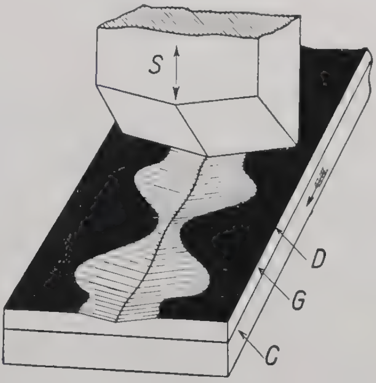

Fig. 6. The principle of sound recording by the Philips-Miller system. The "Philimil" film consists of the celluloid base *C* with the gelatin layer *G* and the very thin opaque covering layer *D*. The cutter *S* vibrating perpendicular to the film cuts a transparent sound track on the film which is moved in the direction of the arrow.

In sound recording by the Philips Miller system, however, a specific difficulty is encountered due to the unavoidable high tension on the strip of film. In order to explain this the principle of the Philips-Miller system must be briefly recalled[3]). The "Philimil" film on which the sound track is cut consists of a layer of gelatin deposited on a celluloid base and covered with a very thin black surface layer (*fig. 6*). A wedge-shaped cutter is moved up and down vertically over the moving film in the rhythm of the sound vibrations, and cuts a groove of varying width in the gelatin layer. By the cutting away of the thin covering layer over the groove thus produced, a transparent sound track is obtained on a black background, which can be scanned in the same way as a photographically recorded (amplitude-modulated) sound track.

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[2]) The sound track is usually recorded separately and then copied on the positive simultaneously with the pictures. Due to the requirement of synchronism between picture and sound however, this does not nullify the requirement that the number of perforations and not the length of film is fixed.

[3]) See also the articles: Philips techn. Rev. **1**, 107, 135, 211, 230, 1936.

The resistance experienced by the cutter in cutting the groove in the film depends on the width of the groove and amounts on an average to 1 kg. This is therefore also the force with which the film must be drawn through the machine. It is obvious that there would be very great danger of sprocket-hole modulation if the reaction against this force were sought in the pull of the sprockets. In the development of the Philips-Miller machines the above-described principle of construction was speedily adopted and the velocity of the film at the spot where the recording takes place is determined by the rotation of a sound shaft. From the high tension on the film it follows that in order to ensure synchronism (with a picture or another sound recording) the sound shaft cannot be driven by the film itself, which is the most preferable method, but only by an adjustable mechanical device.

Because of the lack of necessity of any photographic process in the treatment of "Philimil" film the Philips-Miller system is very suitable for use as a method of sound recording unconnected with cinema film. In particular the system has found an important sphere of application for sound recording in radio broadcasting studios. In this case the problem of film transport is considerably simplified by the disappearance of the requirement of synchronism with a certain picture rhythm. In the construction outlined above therefore the feeding and reeling off of the film by sprocket rollers, and the adjustable mechanical drive may be omitted. The film need not even be perforated. On the other hand the system introduces new demands on the film transport and opens new possibilities which we shall here consider.

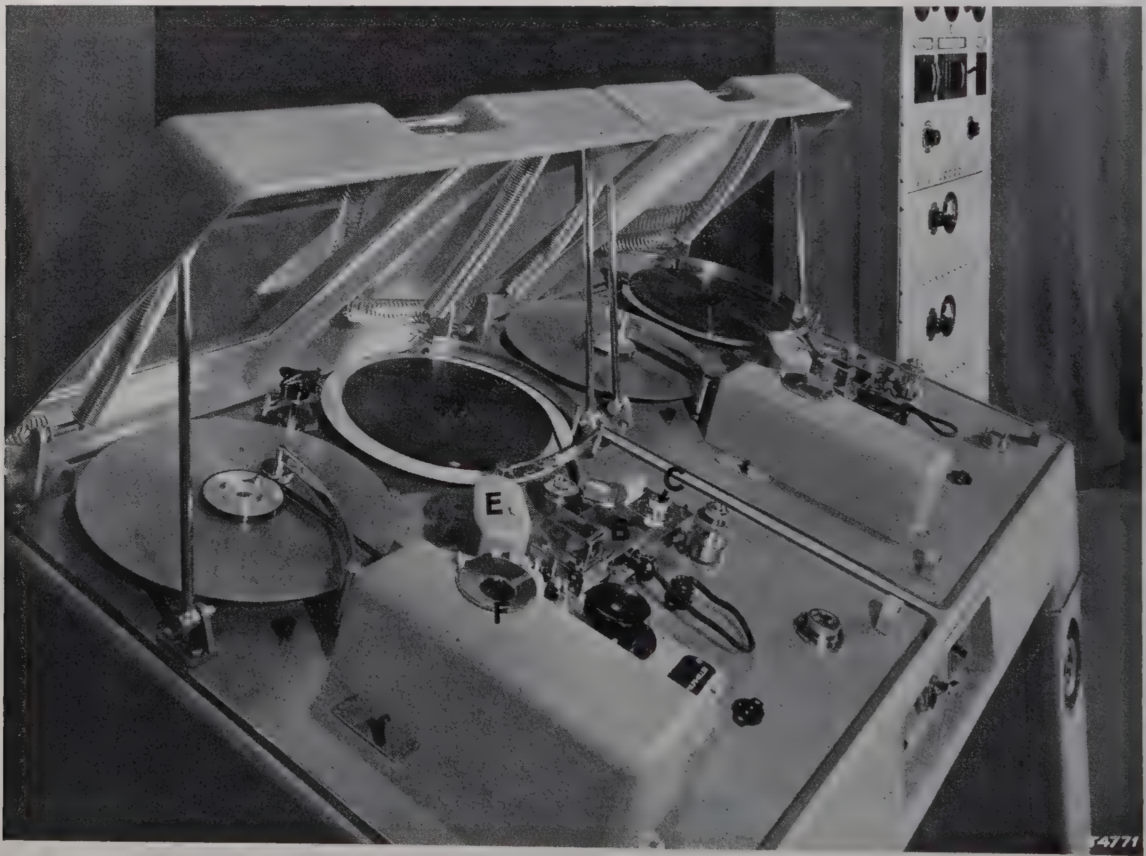

Fig. 7. Machine for sound recording by the Philips-Miller system. The machine. built especially for broadcasting purposes, consists of two quite similar halves each of which is arranged for both recording and reproduction. On the cover plate of each half may be seen the take-up reel to the left and the feed reel to the right. In the middle the sound recorder B which can be displaced by the micrometer screw C with respect to the film in order to adjust the cutting depth of the knife. The lamp and the photocell for scanning the sound track are housed in E and F.

The traject of the film and the driving mechanism of the sound axis

In *fig. 7* a view is given of a Philips-Miller recording apparatus as built for broadcasting studios. *Fig. 8* shows the sound shaft and the sound gate (the same apparatus also serves for the reproduction) on a larger scale. The very simple traject of the film is obvious. Aside from the S-shaped loop which is necessary in order to lay the film on the recording drum fastened to the sound shaft over the necessary large angle, the film runs practically free from one reel to the other. The cutting of the sound track takes place at the point where the film runs on to the recording drum (*s* in fig. 8); the pressure roller which provides the necessary friction between film and recording drum is situated at the point where the film leaves the drum. In contrast to the above described construction for cinema film the sound shaft may here be driven at a constant number of revolutions. It is of course necessary to prevent any vibrations from being transmitted from the driving motor to the sound shaft. The actual construction is shown in *fig. 9*. A driving wheel covered with soft rubber, which thus has a strong damping action, is attached to the shaft of the motor. This wheel presses against the smoothly finished inner surface of the rim of the fly-wheel which is attached to the sound shaft. The weight of the motor is supported by spiral springs which prevent motor vibrations from being transmitted to the cover plate of the machine *via* the frame, and which also supply the necessary pressure between rubber wheel and fly-wheel.

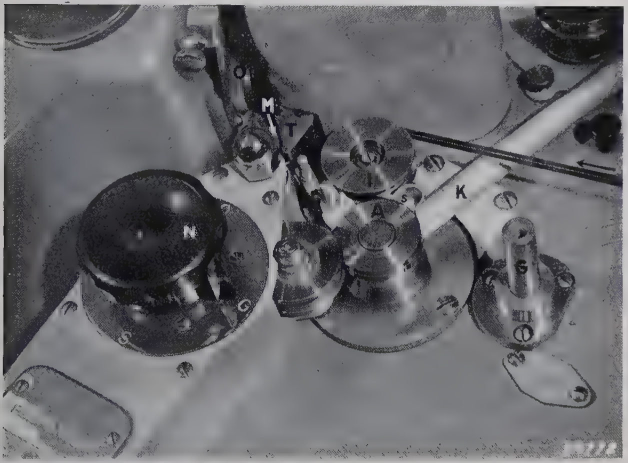

Fig. 8. The sound shaft of the machine shown in fig. 7. The cutter is set on the shaft *G*. In this case it has been removed to show the course of the film more clearly. By means of the fixed roller *I* a loop is laid in the film. This is necessary so that the film may make contact with the recording drum over as great a length as possible. The sound track is cut at *s*; the shaving is removed by suction through the tube *K*. *D* is the pressure roller, *M* the rubber finger for stopping the film. *D* and *M* are moved into position simultaneously by the knob *N*. *T* is the sound gate for scanning, at *O* part of the objective of the optical system may be seen.

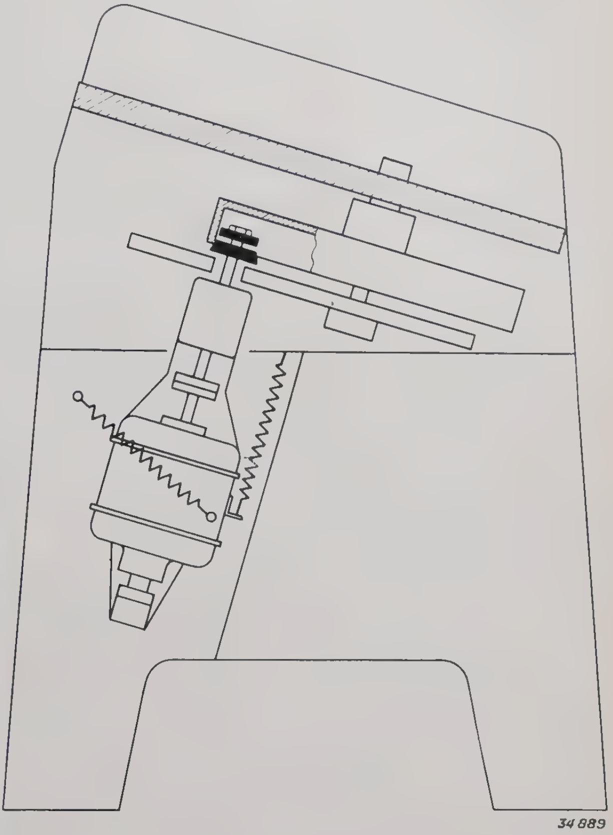

Fig. 9. Driving mechanism of the sound shaft. A friction wheel on the shaft of the motor, whose weight is entirely counterbalanced by springs, is pressed against the inside of the rim of the fly-wheel attached to the sound shaft.

When the machine is started there is a greater friction between the rubber driving wheel and the fly-wheel than when the machine is running at normal speed. In order to prevent excessive wear of the soft rubber wheel, the starting is accom-

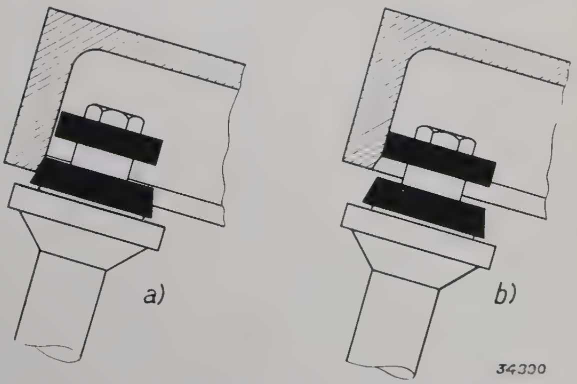

Fig. 10. a) Upon starting, the fly-wheel is accelerated by the conical starting wheel covered with hard rubber.
b) When the fly-wheel is once in motion the motor is allowed to drop slightly, and the fly-wheel is then driven by the driving wheel covered with soft rubber.

plished with a "starting wheel" covered with harder rubber. When the machine is at rest this conical wheel presses against the rim of the fly-wheel, (see *fig. 10a*). When the fly-wheel has been set in motion the whole motor is lowered slightly so that the soft rubber wheel takes over the work (fig. 10*b*).

Moreover it is unnecessary to stop and start the machine anew every time the recording must be interrupted. The moving film can very easily be uncoupled from the sound shaft be raising the pressure roller. When this is done the friction disappears between film and sound shaft, the film lies loosely around the steadily moving recording drum. Thanks to the very small mass of the moving film and the omission of perforations and sprocket roller the film may immediately be brought to a standstill by means of a rubber finger which clamps the film against the sound gate 4) (see fig. 8). Conversely, by lifting the finger and pressing down the pressure roller the film almost immediately regains normal speed. This makes it possible to pass from the reproduction of one film on one machine (fig. 7) without interruption to the reproduction of a second film on a neighbouring machine.

In discussing the principle on which the sound shaft works we have mentioned the condition that it must be very accurately centred in order to avoid irregularities in the peripheral velocity. In the Philips-Miller recording machine much higher requirements are made in this respect, since an excentricity of the recording drum is manifested here not only as a variation in velocity, but, because of the principle used in recording (see fig. 6), as a direct variation in the width of the sound track, with an enlargement of about 40 times. The tolerance is here therefore much smaller than in the former case; it amounts to less than 1 micron. In order to obtain this great precision the bearing is conical. The steel peg upon which the shaft rests is pushed upward by a spring so that the shaft presses lightly against the conical bearing. The shaft thus continues to run centrically independent of any slight wear. The recording drum which is fastened to the end of the sound shaft is very carefully turned after it has been mounted.

The heavy fly-wheel which is fastened to the sound shaft may be undesirable for certain applications, particularly for installations which must be able to be transported. Since it is only a question of the energy which the flywheel accumulates, instead of a heavy fly-wheel on the relatively slowly turning sound shaft, one may in such cases also use a lighter fly-wheel attached to a rapidly turning auxiliary shaft closely coupled with the sound shaft. This method of construction has for example been chosen for machines which are intended only for the reproduction of "Philimil" film.

Velocity of the film transport

While in the case of sound film for the cinema the velocity of the film transport is fixed at about

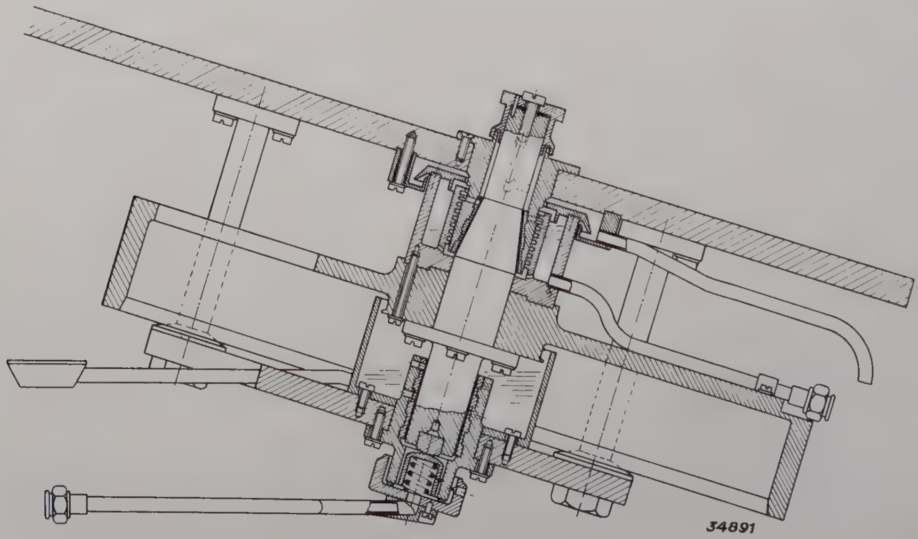

Fig. 11. Bearings and lubrication of the sound shaft. Due to the conical shape of the upper bearing and to the fact that the shaft is pushed against it by a spring under the peg below the end of the shaft, the latter continues to run centrically even after some time. The two bearings of white metal are surrounded by oil reservoirs. The reservoir for the upper bearing rests upon the fly-wheel and thus turns with it. The oil is hereby forced up along a screw thread and flows down along the shaft again. In this way, in spite of the oblique position of the shaft it is well oiled to the very top.

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4) The reel which pulls the film along must of course also stop, the driving mechanism of the reel slips during the interruption.

457 mm/sec by the standardized picture frequency and height, when the Philips-Miller system is used for broadcasting purposes, *i.e.* independent of any synchronization, the velocity of the film may be determined at will. From the point of view of saving material it is desirable to keep the velocity at which the film moves through the machine as low as possible. A velocity of 320 mm/sec has been chosen. It is impossible to decrease the velocity still more without disadvantage to the reproduction of the high frequencies of the sound. The lower the film velocity, the shorter the wave length of the sound track cut in the film at a given frequency. For various reasons the wave length may not fall below a certain limit:

1) A limit is set on the slope at which the cutter can penetrate into the gelatin layer by the size of the angle between the front and back surfaces of the cutter [5]). The ratio between the maximum amplitude and the wave length of the track cut is hereby limited. If a given amplitude is also demanded for the high frequencies, for which the wave lengths are the shortest, a lower limit for the film velocity is automatically prescribed.
2) The finite width of the light streak with which the sound track is scanned causes a certain loss of depth of modulation, which is greater the wider the streak compared with the wave length. The shortest wave length occurring must therefore be sufficiently long with respect to the width of the light streak. This limitation cannot be avoided by making the light streak as narrow as desired (it is 12 to 14 microns wide in practice) because the ratio between the level of interference and the desired signal becomes too large: a particle of dust on the film, for instance, which casts a shadow may then cover too large a proportion of the whole light-transmitting surface of the slit. For the same reason decrease in amplitude mentioned under 1) is even more undesirable.
3) The cutting edge of the knife in recording, and the light streak in reproduction are never both exactly perpendicular to the direction of length of the film. The two small deviations, whose effects must be added together, cause distortion which will be greater, the greater the unavoidable deviations in relation to the shortest wave length occurring.

The three effects mentioned only begin to be disturbing at wave lengths shorter than 40 microns. At the film velocity chosen of 320 mm/sec this corresponds to a frequency of 8 000 c/sec.

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[5]) This has been carefully explained in the article by A. Cramwinckel. The sound-recording cutter in the Philips-Miller system, Philips techn. Rev. **1**, 211, 1936.

TUNGSTEN RIBBON LAMPS FOR OPTICAL MEASUREMENTS

621.326.3 : 535.24 : 536.52

The conditions are discussed which must be considered in the design of tungsten ribbon lamps for use as light sources in various optical measurements. Several different types are described.

For various types of optical measurements a uniformly radiating surface is needed whose intensity must be high and reproducible. Moreover in many cases the relative spectral distribution of the radiation of this surface must also be known. This is the case for instance in subjective and objective photometry, in pyrometry, in spectral photometry and in colorimetry. A few examples will serve to illustrate this statement.

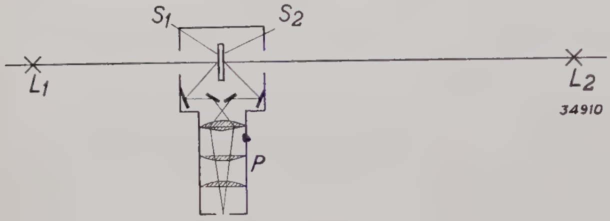

Fig. 1. Arrangement of apparatus for subjective photometry. L_1 and L_2 are the light sources to be compared. S_1 and S_2 are the comparison screens of the photometer P.

In subjective photometry one photometer screen S_1 is often illuminated by the light source L_1 to be measured, and the other photometer screen S_2 by a comparison lamp L_2 (*fig. 1*). The distance between L_2 and S_2 is so adjusted that upon looking through the photometer P the two screens appear to have the same intensity. In order to calculate the ratio of light intensity between L_1 and L_2 the law of the variation of brightness with the inverse square of the distance must be applied. This method involves the following requirements with respect to the comparison lamp L_2:

1) The light intensity must be reproducible.
2) The light intensity must be so high that the required illumination intensity of S_2 is obtained at a distance from L_2 to S_2 large enough to be measured accurately. The minimum value for this distance may be taken as 30 cm for accurate work.
3) The distance to all surface elements of S_2 concerned in the measurement must be very accurately equal, within two per cent if possible, for all points of the luminous surface, in order that it may be possible to use the above mentioned law in the calculation without further corrections. This requirement can easily be satisfied by a small luminous plane surface normal to L_1, L_2 in L_2. When the effective surface of S_2 is a circle with a radius of 10 mm, with a distance of 30 cm from L_2 to S_2 the luminous plane of L_2 must also fall within a circle of radius 10 mm.

The second example is taken from pyrometry. In the case of the much-used optical pyrometer of Holborn and Kurlbaum an image of the radiating body whose temperature is to be determined is projected on the plane of the pyrometer filament. This image and the filament are observed through a red filter by means of a simple microscope or with a magnifying glass. The current through the filament is so regulated that the filament appears just as bright as the image of the radiating body. In calibrating such a pyrometer the relation between the current through the filament and the "black body temperature" [1] of the radiating body must be determined for the "effective wave length" used.

To do this the pyrometer is first set by means of a black body which has been raised to the melting temperature of gold. A small surface having a very great brilliancy is then observed through the pyrometer, and its brightness is then successively dimmed by known amounts. One observes how great the dimming must be in order that the brightness of the surface may be equal to that of the black body at the temperature of melting gold. Making use of Planck's radiation formula the black body temperature of the luminous surface can be calculated at the different degrees of dimming.

Means of carrying out such a calibration will not ordinarily be at hand, while it will nevertheless be considered necessary to be able to check a pyrometer occasionally, while it is in use. This may be done with the help of a calibration lamp which gives a uniform radiating surface large enough for accurate pyrometry. Moreover the black body temperature of this surface must be known for the effective wave length used, when the values of current or voltage of the calibration lamp are specified.

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[1] By "black body temperature" for a given wave length is meant the temperature of a black body which exhibits the same intensity of radiation at this temperature as the body in question.

Not only in primary but also in secondary pyrometer calibration, therefore, is a uniform radiating surface of reproducible high brilliancy needed.

A third example is encountered in spectal photometry. In this type of work it is often necessary, by means of a spectrograph for small wave length regions, to compare the brightness of an unknown light source with that of a comparison lamp of known spectral energy distribution. According to the method of measurement used the slit of the spectrograph must be entirely or partially illuminated by the comparison lamp. In practical cases this is usually accomplished by focussing the image of the luminous surface of this lamp on the slit. Thus here again is there need of a comparison lamp with a sufficiently large, uniformly radiating surface of reproducible high brilliance, whose spectral energy distribution must moreover in this case be known at least relatively.

It has been found that the need for such a lamp with a radiating surface can be met with the tungsten ribbon lamp, and such lamps are in common use for such optical measurements. The incandescent body of these lamps is formed by a tungsten ribbon about 20 μ thick, and for instance 2 mm wide and 20 mm long. This ribbon is heated to incandescence by means of an electric current.

Such a thin ribbon is particularly suitable for the purpose in view. Due to the small area of the cross section the heat conduction is small, so that the cooler sections at the ends are relatively short. Due to the favourable relation between radiating surface and electrical resistance per cm length, high temperatures can be obtained with relatively small currents. It is also important that the whole surface of the ribbon appears equally bright, in contrast to the case of a incandescent wire, where deviations from Lambert's law become appreciable along the edges.

Before we begin to discuss the different designs of tungsten ribbon lamps manufactured by Philips, we shall first examine the radiation properties of tungsten.

Light emission of tungsten

In general the radiation emitted by a substance depends very much upon its temperature. In addition the nature of the surface is also important. Let us consider that portion of the radiation which, at a temperature T, falls within the small wave length region $\Delta\lambda$ in the vicinity of the wave length λ. The current of energy, corresponding to the wave length region $\Delta\lambda$, which is emitted per unit solid angle by a surface element ΔS at an angle Θ with the normal to the surface may be represented by

$$I_{\lambda T\Theta}\,\Delta\lambda\,\Delta S.$$

As has already been mentioned in a previous article ²), the radiation properties of a black body are accurately known. The way in which $I_{\lambda T\Theta}$ depends upon wave length and temperature is given by Planck's radiation formula. Furthermore the radiation of a black body satisfies Lambert's law, according to which

$$I_{\lambda T\Theta} = I_{\lambda T}\cos\Theta \quad . \; . \; . \; . \; . \quad (1)$$

For the radiation of other materials formula (1) is found to be approximately correct for not too large values of Θ. When however Θ approaches 90°, very great deviations may occur.

The radiation of a given substance at wave length λ, temperature T and sufficiently small values of Θ is often compared with that of a black body at the same length and temperature. The ratio of $I_{\lambda T}$ of the substance under consideration to $I_{\lambda T}$ of the black body is called the spectral emission coefficient $e_{\lambda T}$. Since no substance completely absorbs all incident radiation, as is the case with a black body, the emission coefficient is, according to Kirchhoff's law, always less than unity.

The value of $e_{\lambda T}$ for a given substance is found to be dependent on the purity and the degree of smoothness of the surface. Small depressions in the surface act more or less as black bodies, and therefore increase the emission. The smoother the surface the smaller the emission coefficient. In investigations of radiation properties of substances, therefore, one must always strive not only for great purity but also for very smooth surfaces.

In the case of tungsten the physical properties in general and the radiation properties in particular have been the subject of much research. On the basis of the results of these investigations we shall now discuss the questions which are of interest in connection with tungsten ribbon lamps, namely:

1) Is it possible with the help of tungsten ribbon to obtain a radiating surface whose brightness remains practically constant with the passage of time?

2) To what degree are the radiation properties of different ribbons equal?

3) Is it possible to give the relative spectral energy distribution of the radiation of an incandescent tungsten ribbon with reasonable accuracy?

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²) *Cf.* The new unit of luminous intensity, Philips techn. Rev. **5**, 1, 1940.

Reproducibility of the radiation of a tungsten ribbon in the course of time

It is also true of tungsten that the radiation depends upon the nature of the surface. It has been found that at a high temperature it makes little difference in the radiation emission of an ordinary drawn wire or rolled strip whether or not the surface has also been polished. The main point is that such a wire or strip should be "aged" for some time by heating it to a high temperature in a high vacuum or in an inactive atmosphere. During this process a bright shiny surface is formed whose radiation emission is found to be reproducible.

In order to prove this the current was determined of a gasfilled ribbon lamp, the ribbon of which had been heated in a high vacuum during evacuation when the lamp was being made. The true temperature at the middle of the ribbon was 2835 °K. This current was sent through the lamp for 100 hours, while the brightness of the middle of the ribbon was measured as a function of the time. This brightness was found to remain constant within the limits of error of the measurement (0.5 per cent).

Reproducibility of the radiation properties of different ribbons

The reproducibility for different ribbons is important in cases where the spectral emission coefficient must be used, for example, for the calculation of the temperature or of the spectral energy distribution from the black body temperature measured. The spectral emission coefficient $e_{\lambda T}$ must be known as a function of the temperature and wave length. This value is obtained from measurements of $e_{\lambda T}$ which are usually carried out in the investigations in question on several tungsten surfaces. For the wave length and temperature in question values of $e_{\lambda T}$ are found which exhibit slight differences from surface to surface. From these an average value of $e_{\lambda T}$ is found, which may be used in the calculation for any given ribbon lamp.

It is now important to know how great the maximum deviation between the average value and the actual value of $e_{\lambda T}$ will be for this ribbon lamp. The possible deviation consists of two parts. In the first place there is the actual scattering among the values of $e_{\lambda T}$ for different tungsten surfaces such as occurs, and is further heightened by experimental errors, in an investigation of different tungsten surfaces by a single method. In addition there is the possible deviation of the value of $e_{\lambda T}$ assumed to be the average one from the real average value, which may be due to systematic errors in measurement.

When the available material for observation is reviewed, it is found that the possible deviation of the emission coefficient of one ribbon with respect to the average for many ribbons must be placed at 1 per cent.

Furthermore the possible error in the assumed average value of the emission coefficient must be estimated.

Various investigators give different average values. This may be due partially to differences in methods of measurement. Moreover, the different degrees of purity and the different treatment of the surface of the tungsten investigated will play a part. In the case of the tungsten ribbons under discussion it would seen reasonable to give particular weight to the measurements by Hamaker[3]) which were performed on the very material in question. The possible error in the average values given by Hamaker may be considered 1 per cent. Therefore if we use his average value for a given tungsten ribbon, we must take into account a possible error of 2 per cent. This holds for the whole visible region of the spectrum. It is possible that the errors in the infra red and ultra violet regions are somewhat larger.

Calculation of the relative spectral energy distribution

For the calculation of the relative spectral energy distribution the temperature of the tungsten must be determined, the spectral energy distribution of the black body must be determined relatively for this temperature, and the value found must be multiplied by the corresponding spectral emission coefficient $e_{\lambda T}$ of tungsten for every wave length.

An example will show that this method leads to a fairly accurate knowledge of the relative spectral energy distribution.

Let us assume that the black body temperature for a definite, accurately known, effective wave length is 2500 °K, and that this is determined by pyrometry with a possible error of 10°. From this the true temperature is then calculated with the help of a value for the corresponding spectral emissions coefficient which may have an error of 2 per cent. As a result the possible error in the true temperature is increased by 6°. In total therefore the true temperature may contain an error of 16° at the most. Although such an error would be important in the calculation of absolute values of spectral intensities of the black body radiation, it has practically no effect on the relative spectral energy distribution. The only uncertainty which yet remains is the possible error of 2 per cent in the spectral emission coefficient, by which the relative spectral intensity of the black body must be multiplied in order to obtain that of tungsten. This possible error of 2 per cent is valid for the visible region of the spectrum; in the infra red and ultra violet it is probably slightly larger.

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[3]) H. C. Hamaker, dissertation, Utrecht, 1934; L. S. Ornstein, Physica 3, 561, 1936.

For the visible spectral region the calculation of the relative spectral energy distribution of the radiation of tungsten can be shortened with the help of the concept of colour temperature. It has been found experimentally that between 4 000 and 7 000 Å the relative spectral energy distribution of the radiation of tungsten at every temperature T is practically equal to that of a black body at a temperature T_c which is slightly different from T. T_c is called the colour temperature of tungsten corresponding to T. In *table I* T_c is given as a function of T. In order to calculate the relative spectral energy distribution of tungsten, the true temperature is determined and the corresponding colour temperature T_c is found from the table. It is then only necessary to find the relative spectral energy distribution of the radiation of a black body for the temperature T_c in a suitable table.

Table I

T	1200 °K	1600	2000	2400	2800
T_c	1210 °K	1616	2023	2432	2844

From the data here discussed on the radiation properties of tungsten it may be seen that the tungsten ribbon lamp in principle is capable of satisfying the requirements of various optical measurements.

Design and construction of ribbon lamps

In connection with the very divergent applications it has been found desirable to construct different models of tungsten ribbon lamps. The differences lie chiefly in the shape of the bulb, the dimensions and the assembly of the ribbon and the construction as vacuum or gas-filled lamp. We shall discuss these points separately.

Shape of the bulb

When no very great demands are made of the optical focussing of the ribbon, and when moreover the spectral transmission curve of the wall of the bulb need only be known roughly, the simple cylindrical bulb shown in *fig. 2* may be used. This bulb is usually made of heat resistant glass. For the case in which the lamp must also be used in the ultra violet for wave lengths shorter than 3 500 Å or in the infra red for wave lengths longer than 25 000 Å a bulb of clear quartz may be chosen.

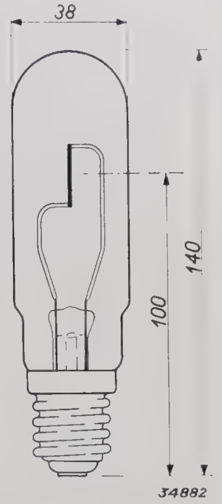

Fig. 2. Ribbon lamp with cylindrical bulb. The dimensions are indicated in mm.

If the optical focussing of the ribbon is important the horn-shaped bulb with the plane window fused on (*fig. 3*) is to be recommended. The radiation of the ribbon in this case passes through a ground plane parallel window which is fused to the bulb. The shape of the bulb is so chosen that the radiation from the back of the ribbon, which is reflected by the rear wall does not pass through the window. The combination of these two precautionary measures makes it possible to focus the image of the ribbon very well, and also makes it possible in the photometric application to apply

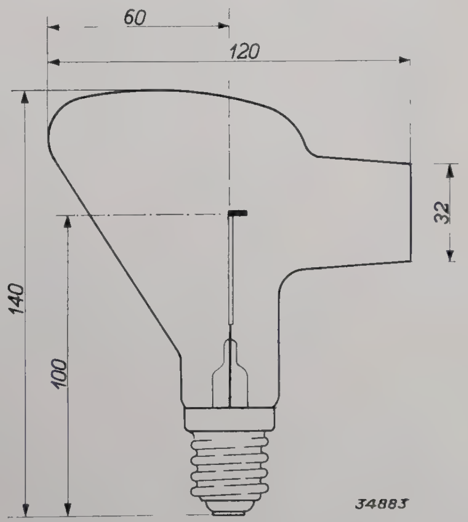

Fig. 3. Ribbon lamp with horn-shaped bulb provided with a fused-in plane window. The maximum transverse dimension of the bulb is 42 mm.

accurately the law of the variation of the intensity of illumination with the inverse square of the distance. The plane parallel window is made of heat resistant glass or quartz. In precise measurements it may be necessary to correct the spectral energy distribution of the radiation of the ribbon for the absorption by the window. To do this the spectral transmission curve of the window must be determined before it is fused into the bulb.

In spectral photometric investigations the bulb shown in *fig. 4* with two oblique plane windows may often be used. In such work it is often necessary to focus the image of the light source being investigated on the plane of the tungsten ribbon, and then to focus the image of this plane again on the plane of the slit of the photograph. With a vertical slit and a horizontal ribbon it is possible to illuminate part of the slit by the ribbon and the rest by the unknown source. When the bulb shown in fig. 4 is used the optical focussing through the plane windows is able to satisfy high requirements. By the oblique position of the window in the way shown in the figure disturbing reflections from front and rear walls are avoided. Windows of heat resistant glass or quartz may be used as in the horn-shaped bulb. The spectral transmission curve of each individual window may if necessary be determined before it is fused in.

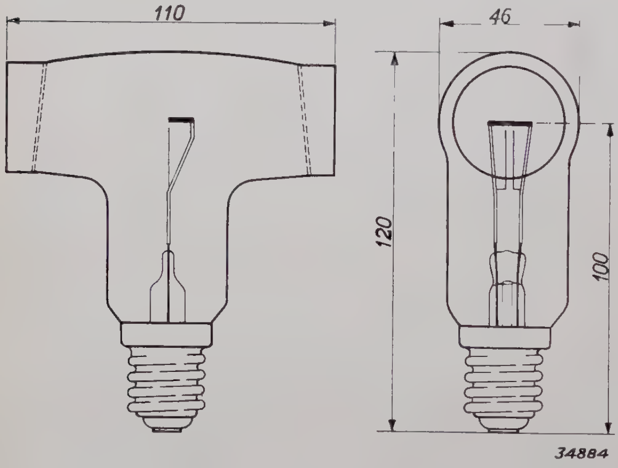

Fig. 4. Side and front views of a ribbon lamp with a bulb provided with two oblique plane windows. The dimensions are given in mm.

In photometers of small dimensions, in simple spectral photometric arrangements and in many other cases there exists a need for a ribbon lamp with a small bulb and low power. This need is met by the lamp with small spherical bulb (*fig. 5*) which is made exclusively of calcium glass and in which only ribbons 0.5 mm wide are mounted.

Assembly and dimensions of the ribbon

The assembly is carried out in general as follows. Each end of the ribbon is welded to a nickel pole which must be relatively thick, since otherwise the temperature of the nickel at the weld would exceed the maximum permissible temperature for this metal.

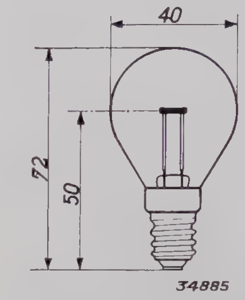

Fig. 5. Ribbon lamp with small spherical bulb.

The temperature at the ends of the ribbon naturally exhibits a sharp gradient due to the flow of heat toward the poles. In certain measurements these cooler end pieces might have a disturbing effect. In order to prevent this the ribbon is bent at both ends as shown in *fig. 6*. In this way the cooled ends are screened by the middle section of the ribbon whose radiation is to be used. By this means it is also brought about that the expansion of the ribbon upon heating has practically no tendency to cause disturbing stresses or deformations. The length of the ends bent under is always 5 mm. The useful length of the ribbon may be 10 or 20 mm, and its width 1 or 2 mm, in some cases 0·5 mm.

In choosing the most suitable ribbon lamp for a given application from the models given in *table II*, various factors must be considered. For spectral photometric uses the conditions of the desired optical focussing will be decisive. If the image of the ribbon is focussed transversally across the slit, a short ribbon is sufficient. If a vertical ribbon must be focussed on the slit a long ribbon is usually preferable.

In general photometric work the desired total luminous intensity may be the deciding factor.

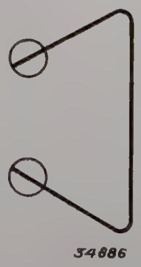

Fig. 6. The ribbon is bent so that the cooler end pieces are screened by the middle of the ribbon.

In any case the ribbon should always be chosen as small as possible in order to avoid unnecessary consumption of current. For many applications it is desirable that a certain point on the ribbon, usually the middle, should be indicated. In all lamps with a useful ribbon length of 20 mm such indication may be introduced in the form of a point of wire at one side in the plane of the ribbon.

Table II

Bulb	Width of ribbon in mm	Position of ribbon	Useful length of ribbon in mm
Cylindrical model of heat resistant glass or quartz	2 or 1	horizontal or vertical	10, 10 or 20*
Horn-shaped model with one plane window of heat resistant glass or quartz	2 or 1	horizontal or vertical	10 or 20*
Model with two oblique windows of heat resistant glass or quartz	1	horizontal	20*
	0.5	horizontal	10*
Small spherical model of calcium glass	0.5	horizontal	10

*) With index at the middle of the ribbon if desired.

Vacuum lamp or gas-filled lamp

The tungsten ribbon lamps may be vacuum lamps or gas-filled lamps. In general a gas-filled lamp will be preferred because with the same life a higher working temperature and thus a greater brightness can be obtained than with a vacuum lamp. For spectral photometric work in the blue and ultra violet this is an important advantage.

As we have already seen the gas has no harmful effect on the reproducibility of the radiation in the course of time if the lamp is always allowed to burn in the same position. The gas does, however, have some influence on the temperature distribution of the ribbon. In the vacuum lamp this temperature distribution is determined by accidental slight irregularities in dimensions and properties of the ribbon and by the flow of heat toward the poles. In the gas-filled lamp the flow of the heated gas is also an influential factor. In the most unfavourable case, namely that of a gas-filled lamp with a vertical ribbon 2 mm wide and 20 mm useful length, at an average temperature of 2 500 °K, the upper end of the ribbon is not more than 25° warmer than the lower end. This difference in temperature is however not important.

Due to the dissipation of heat by the gas a larger current must be used to obtain a given temperature with a gas-filled lamp than with a vacuum lamp. For example, in the case of the gasfilled lamp with a ribbon 2 mm wide, a normal working temperature of 2 800 °K is reached with a current of 17.5 A, a temperature of 2 300 °K with 12.8 A. In the case of a vacuum lamp a normal working temperature of 2 300 °K is reached with a current of 10.8 A.

Compiled by J. VOOGD

MEASUREMENTS IN THE PHILIPS RARE GAS PLANT

by H. C. A. HOLLEMAN.

545.7 : 661.93

In connection with the manufacture of electric lamps large scale measurements must be carried out in the Philips rare gas plant on the composition of mixtures of argon and nitrogen. Two methods used in these measurements are described in this article. The first is based upon a determination of the specific weight of the mixture with the help of a spring scale, and the second upon a measurement of the vapour pressure of the mixture at the temperature of boiling oxygen.

In carrying out the measurements necessary for the control of products or of the process of manufacture methods are used in many industries which differ very much from the ordinary laboratory methods. This is due on the one hand to the fact that the methods have been adapted to the peculiar requirements of the industry, and on the other hand to the fact, that use may be made of possibilities not otherwise offered. Both factors have played their part in the Philips rare gas plant in determining the choice of methods to be applied to determine the composition of gas mixtures.

One of the most important gas analyses is the determination of the composition of argon-nitrogen mixtures which are used as filling for electric lamps, the argon content of which influences the efficiency of the lamps. Great accuracy or sensitivity of the measuring method is in general not demanded. It is however desirable that the measurement should be rapid and capable of being performed without too great skill.

In an earlier article in this periodical [1]), it was stated that the composition of an argon-nitrogen mixture can be determined chemically with the help of metallic lithium, which has been brought into a condition in which it is able to absorb large quantities of nitrogen. This method is suitable for very precise measurements (which, however, also demand considerable time and experience), and also for the determination of very small quantities of rare gas. It is therefore suitable for controlling the purity of nitrogen.

For the purpose outlined above, namely the rapid and easy determination of large as well as of small quantities of argon in nitrogen, the method mentioned is less appropriate. Since, however, we are here concerned with a mixture consisting of two gases only, the analysis may also be carried out physically by measuring some physical quantity which varies in a definite way for different proportions of the gases in the mixture from 100 per cent nitrogen to 100 per cent argon. Two quantities have been found suitable: the specific weight and the vapour pressure of the mixture.

Anlysis of argon-nitrogen mixtures by a determination of the specific weight

The specific weight of nitrogen (with respect to air) is 0.9672 and that of argon 1.3796. The difference is thus 0.4124, and 1 per cent difference in composition gives a change of 0.0041 in the specific weight. This shows, that the determination of the specific weight must take place with an accuracy of several tenths of one per cent.

A very easy indirect method of determining the specific weight of gases is that of Bunsen-Schilling, in which the velocity of effusion through a small aperture is measured. At a given difference in pressure and a given temperature this velocity is inversely proportional to the square root of the specific weight. The internal friction and other factors, however, prevent strict application of the law, so that no greater accuracy than 1 to 2 parts in the second decimal place can be attained. The method is therefore useless for our purpose.

A direct determination of the specific weight, consisting of accurate weighing of a bulb filled with gas would be accurate enough, but it is fairly elaborate and requires great skill in execution. Instead of filling the bulb with the gas being analyzed, a simplification was attained by determining by a weighing process the lifting force experienced by a closed bulb in an atmoshere of the gas in question. A further simplification is obtained by determining the pressure which the gas in question must have in order to have the same specific weight as dry, carbon dioxide-free air at the same temperature and atmospheric pressure. If the air and an argon-nitrogen mixture have the same specific weight at the same temperature then the ratio of their pressures is a direct measure of the composition of the argon-nitrogen mixture. It is hereby assumed that Boyle's law is strictly valid, which is permissible in this case. If the measurements are to be very accurate, and if one is working with easily condensible vapours, it may be necessary to take into account deviations from the laws for perfect gases.

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[1]) Philips techn. Rev. 4, 128, 1939.

It was finally found possible to simplify the weighing without too great a loss in accuracy by using a spring scale instead of an ordinary balance with a swinging beam.

In *fig. 1* the main details of the apparatus are shown. *a* is a column containing gas whose specific weight is to be determined. In this column hangs a spiral spring *b*, which carries the bulb *c*. The extension of the spring is a measure of the weight of the bulb diminished by the upward pressure of the gas in question. This pressure is equal to the specific weight of the gas multiplied by the volume of the bulb.

In order to read off accurately the extension of the spring a microscope *d* is used with a horizontal cross hair. With the microscope one observes a horizontal piece of wire fastened to the spring and the pressure of the argon-nitrogen mixture can be adjusted until this wire coincides with the cross hair of the microscope.

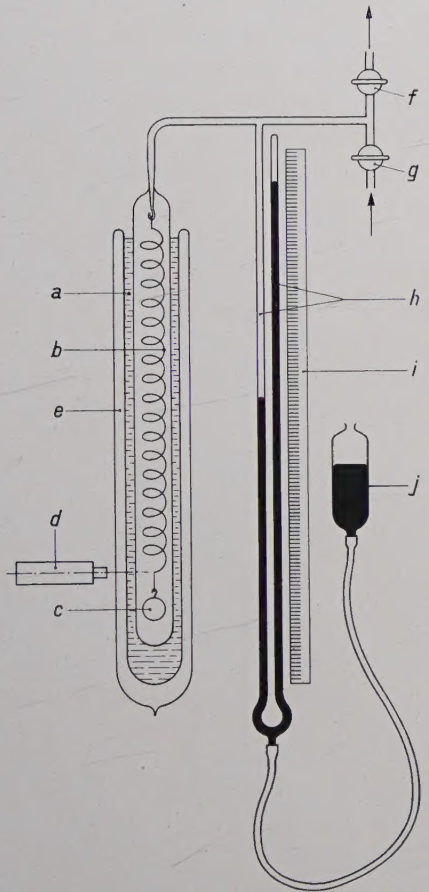

Fig. 1. Apparatus with spring scale for the measurement of the specific weight of gas mixtures. *a* tube which is filled with the gas *via* the stopcock *g*; *b* spring (molybdenum wire); *c* bulb, upon which the gas exerts an upward pressure proportional to the specific weight; *d* microscope with cross hair for observation of the position of the spring; *e* Dewar jar filled with water to keep the temperature of the gas constant: *f* exhaust tap connected with vacuum pump; *h* tubes of a manometer for observing the pressure of the mixture measured; *j* mercury reservoir which can be raised and lowered in order to change the pressure of the mixture slightly and in that way to make the index on the spring coincide accurately with the cross hair.

In order to maintain a constant temperature in the column *a*, it is surrounded by a water bath in a Dewar jar *e*. The Dewar jar is silvered except for a strip in front of the microscope. The column can be evacuated through the stop cock *f*, and the gas to be examined may be admitted through *g*. The pressure is read off from the mercury manometer *h* with scale *i*. By moving the reservoir *j* up and down the pressure can be slightly varied with *f* and *g* closed.

The spring was originally made of quartz since this material is particularly suitable due to its small elastic inertia and its chemical stability 2).

Later, when it was discovered that molybdenum could also be used, its use was adopted since the great brittleness of the quartz was found to be a disadvantage. The spring must of course be extremely flexible in order to have sufficient sensitivity. For the same reason it is desirable to make the volume of the bulb as large as possible. On the other hand the bulb may not be too heavy since otherwise the flexible spring would be loaded beyond its limit of elasticity. The molybdenum wire used has a thickness of 0.12 mm and is wound with a low pitch 17 turns around a mandrel 28 mm in diameter. The sensitivity amounts to about 1 mm extension for a load of 1 mg. The bulb weighs about 300 mg and thus produces an extension of 300 mm. This extension does not exceed the limit of elasticity. The volume of the bulb is about 15 cc. The upward pressure of atmospheric air (760 mm and 20° C) on the bulb is thus about 18 mg. 1 mm variation in pressure thus gives a variation in upward pressure of $18/760 = 0.02$ mg, corresponding with a displacement of 0.02 mm of the mark on the spring. This displacement can just be observed through the microscope and thus corresponds approximately with the limit of accuracy of the apparatus. The same limit is also given by the accuracy with which the gas pressure may be read. Since 1 mm Hg is about 0.13 per cent of the total pressure ($\sim$1 atmosphere), and since a change in the composition of the mixture by 1 per cent corresponds to a change in pressure of 0.4 per cent, it is clear that the composition of an argon-nitrogen mixture can be determined with an accuracy of about 0.3 per cent.

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2) Philips techn. Rev. **1**, 126, 1936.

In order actually to attain this accuracy it is very important that the spring should be free of elastic inertia and that the bulb should not be appreciably deformed upon variations in pressure. This has been studied in numerous test measurements. Within the limit of observation of the apparatus no error was found. The temperature sensitivity is of course very great, even more than 1/273 per °C, probably because the elasticity of the molybdenum decreases with increasing temperature. Thanks to the water jacket and the Dewar jar, however, the temperature remains sufficiently constant so that the temperature effect is not disturbing.

A great advantage of the spring scale over a beam balance is that it is practically aperiodic. If the equilibrium is disturbed, due to increase in pressure for instance, the scale is seen to execute several vibrations with a period of about $^1/_2$ sec; within a few seconds, however, the movement is so strongly damped that it cannot be observed even with the microscope. The vibration of the mercury in the manometer usually lasts longer than that of the spring.

The total length of time needed for a measurement is about 5 minutes. Great skill is not required of the operator. The same amount of time must be allowed for the preceding calibration of the apparatus with dry air free of carbon dioxide. Calibration, however, needs in general only be carried out once for a whole series of measurements.

It is obvious that other gas mixtures than argon-nitrogen can also be investigated with the spring scale. If for example mixtures containing hydrogen are measured, the specific weight of the gas in question may be considerably smaller than that of air at 1 atmosphere. In that case, in order to make the comparison with air, the gas mixture being measured would have to be put under a pressure of several atmospheres, which is undesirable in connection with the lightness of the construction of the bulb. In such a case therefore it is advisable to admit air to a pressure of less than 1 atmosphere; this means that the microscope must be lowered slightly.

Analysis of argon-nitrogen mixtures by the determination of the vapour tension

Since liquid oxygen is produced in large quantities in the Philips rare gas plant, it is always possible to realize the temperature of the boiling point of oxygen, namely —183° C. The boiling point of argon lies directly below that of oxygen, namely at —185° C. If argon is brought to the temperature of boiling oxygen, its vapour tension is slightly greater than 1 atmosphere. It is actually found that condensation only occurs at a pressure of 1050 mm. With increasing proportion of nitrogen in an argon-nitrogen mixture the vapour tension increases. Pure nitrogen has a vapour tension of 3.6 atmospheres at the temperature of boiling oxygen.

If it is desired to determine the composition of a gas mixture by finding out at what pressure the mixture begins to condense, it must be kept in mind that the composition of the product condensed is not in general the same as that of the gas. The less volatile component, in our case argon, shows a tendency to become concentrated in the fluid, while in the gas a decrease in the proportion of argon

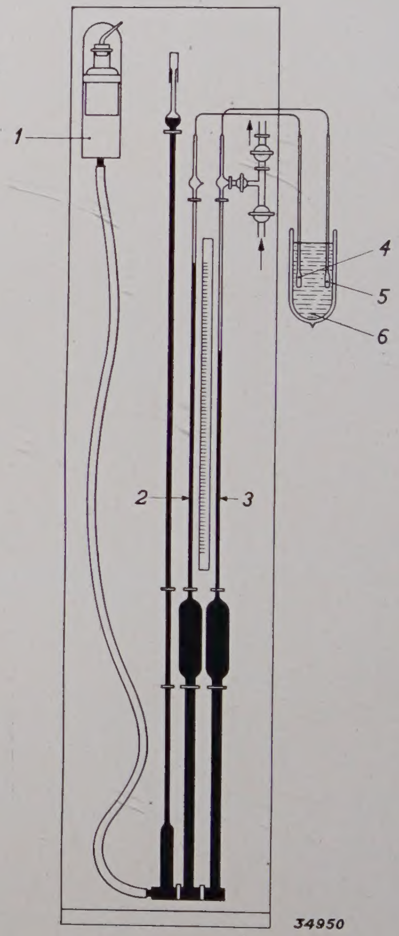

Fig. 2. Apparatus for the determination of the vapour pressure of argon-nitrogen mixtures. By lowering the mercury reservoir *1*, the mercury is allowed to flow out of tubes *2* and *3*. Tube *2* is permanently filled with pure argon, while tube *3* is filled with the mixture under consideration *via* the stopcocks. After the stopcocks have been closed the mercury reservoir is raised again. The wider portions of tubes *2* and *3* are thereby filled with mercury and the gas displaced is driven through narrow capillaries into tubes *4* and *5*, respectively, which are immersed in liquid oxygen (Dewar jar *6*).
Since the gases in these tubes condense, the position of the mercury column in tubes *2* and *3* indicates the vapour pressure of pure argon and of the gas under consideration, respectively. The scale is calibrated in per cent of nitrogen. In tube *2* the mercury column must therefore stand at zero, which forms a check on the purity of the boiling oxygen in the Dewar jar.

occurs. Only when the condensation is nearly complete, can the composition of the fluid be said to correspond to the original composition of the gas.

This is the principle upon which is based the determination of the composition of argon-nitrogen mixtures by means of the apparatus shown in *fig. 2*. The measurement is begun by lowering the mercury reservoir *4* so that the mercury column *3* runs empty and the widened part of the column is filled with the mixture to be measured. When the stopcocks are now closed and the mercury container again raised, the gas mixture is almost completely condensed in tube *6* which is immersed in boiling oxygen. The height assumed by the mercury column is a measure of the vapour pressure of the mixture.

In *fig. 3* the vapour pressure of the argon-nitrogen mixture is given as a function of the composition. According as one considers the abscissa as the composition of the fluid or the vapour, the upper or the lower curve is obtained. We are concerned with the first case, and thus observe that the vapour pressure increases almost linearly with the concentration of nitrogen. At about 10 per cent nitrogen the accuracy of the apparatus is about 0.3 per cent. For larger contents in nitrogen the apparatus cannot be used because the vapour pressure becomes too high. Moreover, the equilibrium between the fluid phase and the gas phase, which are joined only through a narrow capillary, becomes established with more and more difficulty as the difference in composition between the two phases becomes greater. This difference increases with the concentration of the nitrogen which therefore must not practically be greater than 25 per cent.

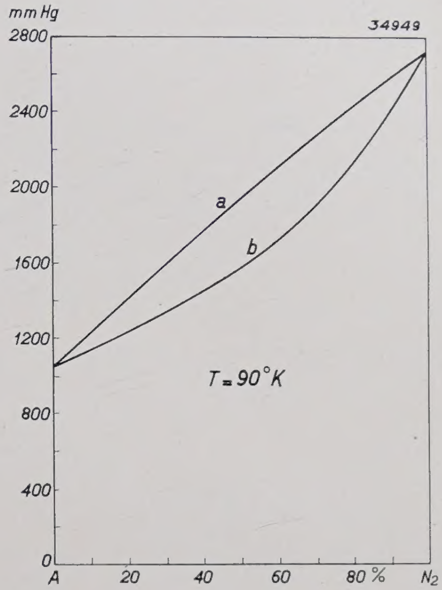

Fig. 3. Vapour pressure of argon-nitrogen mixtures as a function of the composition *a* of the liquid, *b* of the gas.

The great advantage of the apparatus is that it works very rapidly. One determination takes only about 2 minutes, and after some practice can be carried out by any one.

ABSTRACTS OF RECENT SCIENTIFIC PUBLICATIONS OF THE N.V. PHILIPS' GLOEILAMPENFABRIEKEN

1447: H. C. Hamaker: Adsorption of iodine vapour by powders (Rec. Trav. Chim. Pays Bas **58**, 903-916, July-Aug. 1939).

According to a method developed by J. H. de Boer samples of powders which had been heated in a vacuum were exposed to iodine vapour. The iodine was adsorbed on the surface of the powder. The amount adsorbed is determined by a simple chemical titration. The necessary precautions, as well as the degree of reproducibility of these processes is described in great detail. Surface reactions and the influence of grinding in a ball mill can be studied by means of the corresponding changes in adsorption.

1448: E. J. W. Verwey: Electronic conduction of magnetite ($Fe_3 0_4$), and its transition point at low temperatures (Nature, London, **144**, 327-328, Aug. 1939).

The electronic conduction is determined for different oxides of iron of the Fe_30_4 type. This is important from a theoretical standpoint, since Fe_30_4 is an abnormally good semi-conductor, possesses a remarkable crystal structure in which there is probably a statistical distribution between tri and bivalent iron ions at equivalent lattice positions, and in addition seems to have a transition point in the neighbourhood of 120° K.

1449: J. D. Fast: The appearance of two new branches of metallurgy as a result of the development of the electric lamp industry (Metaalbewerking **6**, 116-120, 132-139, 145-150, 159-162, 174-176, 189-192 and 203-205, June-Sept. 1939). Original in Netherlands language.

Two branches of metallurgy have appeared as a result of the need felt by the developing electric lamp industry of being able to manufacture wire out of the metals with high melting points. In these articles a survey is given of the history of their development and the most important applications. For the contents of the articles the reader may be referred to Philips techn. Rev. **3**, 353, 1938 and **4**, 321, 1939.

1450: A. H. W. Aten jr.: Artificial radioactive substances as indicator (Chem. Wbl. **36**, 607-609, Sept. 1939). Original in Netherlands language.

In this lecture given before the Nederlandsche Natuur- en Geneeskundig Congres (April 1939), it was explianed how it is possible to follow certain atoms in their course through the body by adding small quantities of artificial radioactive substances. It is for example possible to study the way in which substances containing phosphorus distribute themselves throughout animal organisms.

1451-1453: J. M. Stevels: Cold flames. (Chem. Wbl.) **36**, 638-642, 654-657, 657-663, Sept. 1939). Original in Netherlands language.

This is a review of theory and practical research on flames such as occur in gases at very low pressure. These flames differ from ordinary ones by the absence of an ignition temperature. In order to keep such a so-called cold flame cold, it is necessary to remove the heat developed by the reactions occurring so rapidly that the temperature does not rise appreciably. A cold flame is a very suitable medium for the investigation of reaction velocities, and also of the nature of the chemical bond in general, as is discussed at length in the last article.

1454: J. Boeke and H. van Suchtelen: Direct rapid chemical Analysis with the mercury dropping electrode. (Z.Elektrochem. **45**, 753-756, Oct. 1939). Original in the German language.

Compare Philips techn. Rev. **4**, 231, 1939 for the contents of this article.